# * System units

[1] international system (SI)

- distance (metre)

mile = 1609 m

- force (Newton) or Kg m/sec

- Power (watt) or N·m/sec

- mass (Kg).

- tonne = 1000 Kg

- acceleration of gravity $g = 9.81$ m/sec$^2$

- velocity m/sec or mile.p.h

* British system

- distance (ft)

inch = 2.54 cm

yd = 3 ~~inch~~ feet

Foot = 12 inch

mile = 1760 yd

= 5280 ft

- force (Ib.wt)

- power (Ib.wt.ft per sec)

* mass (poundweight) (Ib)

1 tons = 2240 (Ib.wt)

: acceleration of gravity ($32.2\ ft/sec^2$)

- velocity (ft/sec)

* torque produced by Motors:

$$T_m = T_L + T_f + J\frac{d\omega}{dt}$$

$T_L \Rightarrow$ عزم الحمل

$T_f \Rightarrow$ عزم الدوران الناشئ عن الاحتكاك

$J\frac{d\omega}{dt}$ عزم التعجيل الذاتي

وهو العزم المسبب للتسارع الزاوي ويتلاشى عند الدوران بسرعة منتظمة

$$T_m = T_L + T_f$$

$$v = \omega \cdot r$$



* Types of Motors used in Electric traction

[1] dc Motors

تتميز بأنها تدور بالسرعة المطلوبة بدقة

ذات مدى واسع لتغير السرعة

- أمكانية عكس أتجاه حركتها الدورانية

- تميزها بعزم بدء حركة مناسب

[2] Induction Motors

- Squirrel Cage rotor مناسب للتطبيقات التي تحتاج لسرعة دوران ثابتة

- wound rotor " " " " عزم بدء كبير مع تقليل من قيمة تيار البدء

[3] Synchronous Motors

مناسب للتطبيقات التي تحتاج سرعة دوران ثابتة حقيقية

وقدرات كبيرة ، امكانية تصميمها عند سرعات واطئة بمعامل

قدرة عالي وكفاءة تشغيل مرتفعة

## * General ch's of Electric traction Motors:

a) High starting torque

للتغلب على المقاومة والوصول إلى السرعة المطلوبة

b) Series ch's between torque and speed

T (N.m)

$T_0$

$T_1$

$n_0$ $n_1$ n (r.p.m)

Series ch's

T (N.m)

$T_0$

$T_1$

$n_0$ $n_1$ n r.p.m

Parallel ch's

- لو كان هناك محركين متماثلين ولكن نظراً للاحتكاك نجد أحدهم يدور بسرعة أعلى من الآخر ولتكن $n_0$, $n_1$

1- إذا كان المحركين لهما خواص التوازي نجد أن الفارق من العزم كبير فالموتور الذي تكون سرعته أعلى تكون ذو عزم صغير وعليه لا يتم توزيع الحمل unfairly

2- إذا كان لهما خواص التوالي نجد أن الفرق بين العزمين صغير وبالتالي هناك توزيع متساوي للحمل على الموتورين

ولذلك يفضل الموتور series عند الأحمال الكبيرة لأن العزم يتناسب عكسياً مع السرعة $T \propto 1/\omega$

[illegible]



(c) easy to control in speed

d) has ability to using electric breaking.

e) " " " standing suddenly change in voltage

(f) " " " standing cutting off source of supply

تحمل الانقطاع المؤقت لمصدر التيار

لأنه $E_b$ تكون قد اختفت كهرباء قيمتها الأولى سالب

سريان تيار كبير بالمحرك

(g) hardness, weight and volume

كلما انخفض وزن المحرك كلما قل الإمكان لسهولة تثبيته

ولسهولة حركته وصغر المكان المخصص لتثبيته

## * System of electric traction

can be divided according to getting their power to main groups.

(a) Vehicles generate its own Energy and subdivided according to the nature of generation or storage

diesel [illegible] - electric train or ships
- petrol electric trucks, lorries
- the battery - driven road vehicles

(b) vehicles recieve their power from distributing network fed by a few large generating stations

- dc station } tramways - rail ways
- ac station } trolley buses

## * types of power supply used in electric traction.

(a) dc current system

600 - 700v (tram) داخل المدينة
1500 - 3000v. (trolley) خارج المدينة

(b) Single phase system

11 - 15 Kv with $f = 16\frac{2}{3}$ (Hz) or 25 Hz

تحتوى على كبل ضاغط 300-400 ويستخدم التردد المنخفض

لتحسين الكفاءة ، p.f وكمحسن الشرارة الكهربائية بين الموصل والفرش

وتقليل X وبالتالي تقليل الفقد في الجهد . وتقليل التداخل بين الشبكات

(c) three phase system.

3.3Kv $f = 16\,2/3$ Hz

لتجنب قطع الهوائيات والتغلب هو الخط الثالث مع الأرضي

أسباب التردد



## * Advantges of Electric traction.

1- it is a cleanliness so it essential for use in underground and tube railways
النظافة المصاحبة للحركة الكهربائية

2- rapid & smooth acceleration and braking
يعتمد على التغير في السرعة

3- have a large speed than steam traction electric
traction → 1-20 M.p.h
steam.t → 0.4 → 0.5 M.ph

4- easy to stop specially in frequent stops
سهل التوقف أو الحركة خصوصاً مع تكرار التوقف في المدن
والقطارات.

5- need less time for maintenance and repair
So less cost to maintanence and repair by 50%

6- Can carry more people than steam traction because of higher average speed.
نتيجة زيادة معدل السرعة فيسمح بزيادة حمل الأكثر.

7- it can be used immediatly at any time it connected to supply so better utilization

8- No smoke or sparks and no damage to building due to smoke fumes so it is safety

9- Saving in cost and energy due to absence of coaling and water depots (خزانات الديزل) and also time of coaling of engines.

10- the electric braKing method is better than mecanical breaking due to

- less wear on brake shoes
- less heat wasted in the brake shoes

## * Didsadvantges of E.T.

1- High cost required to convert from steam to electric traction due to over head equipement and feeders.
تكاليف إنشاء عالية

2- failure in power supply for a few minites may cause cut off servies for hours so increase reliability of supply

3- Formation of ice layers on conductor rails will prevent the train to get it's power, this can be overcome by runing a service locomotive up and down the line to prevent Ice formation

4- the interferance between the power line with telephone and telegraph lines runs along the track So high cost for moving lines away the tracks or replaced by cable.

5- require a power for heating the Compartments (تدفئة) at high cost
مكتير من الجر بالبخار لأنه لا يستغل البخار من هذه العملية



## * Mechanices of train movement:

$$T = F' * \frac{P}{2}$$

$$F' = \frac{2T}{P}$$

gear efficiency

$$\eta = \frac{F D/2}{F' d/2}$$

$$\eta = \frac{F}{2T}\left(\frac{P}{d}\right) D$$

Armature
Pinion
gear wheel
road wheel (driving wheel)
$F'$, $P$, $d$, $D$, $F$

$G = d/P$ gear ratio

$$\eta = \frac{F}{2T}\frac{1}{G} D \Rightarrow F = \eta 2T \frac{G}{D}$$

$$F_t = \eta T * \left(\frac{2G}{D}\right) \quad \#$$

tractive effort on driving wheel

عبارة عن driving wheel (D) ( تمثيل ! tractive effort ⇐ F'

gear wheel (d)

$\eta_{ad}$ (cofficient of adhesion) = $\dfrac{\text{tractive effort to slip the wheel}}{\text{adhesive weight}}$

معامل الالتصاق — وزن التصاق

| Speed m.p.h | 0 | 10 | 20 | 30 | 40 | 50 |
|---|---|---|---|---|---|---|
| $\zeta_{ad}$ | 0.25 | 0.16 | 0.14 | 0.12 | 0.10 | 0.09 |

if rails are greasy ( مشحم ) the value is 0.08

Ex) if train has weight m (tons) and third of weight is driving wheel
what the max acceleration of $\zeta_{ad}$ 0 → 0.25

Solution.

$\zeta_{ad} = F/W$ $\quad F = \zeta_{ad} W$

$m * a = \zeta_{ad}\, m * g$

$a = \zeta_{ad} * g$

$= 0.25 * 32.2 = 8.1$ Ft/sec/sec

$= 8.1 \frac{0.3 * 0.62 * 3600}{1000}$ mile/h/sec (km, mile)

$a = 5.5$ m.p.h.p.s

max acceleration

as $5.5 * 1/3 = 1.83$ m.p.h.p.s



- For steam traction the adhesive weight less than 50%

$\zeta_{ad}$ (electric traction) > $\zeta_{ad}$ (steam traction)

- this is because:

1- the torque in electric traction is continous while in steam traction is pulsating.

2- in E.T the driven wheels are distributed along the length of train while in steam traction they are close together.

M M M M M

engine M

* **Tractive effort required to move the train**

$F_t = F_a + F_r \pm F_g$

$F_a$ — the required T.Eff for linear acceleration
القوة اللازمة للتسارع الخطي

$F_r$ — the required T.Effort to overcome the train resistance
للتغلب على قوة المقاومة لحركة القطار

$F_g$ — the required T.Effort to overcome the acceleration of gravity
+ صعود
− نزول

## • Fa calculation:

if a force (fa) (Ib·wt) acts on a mass of w (tons) the acceleration is (a):

$$a = \frac{Fa}{m} = \frac{Fa}{(w/g)} = \frac{Fa\,(32.2)}{2240\,w} \rightarrow \text{Ft/sec/sec} \;\; \frac{3600}{5280}$$

$$a = \frac{Fa}{w}(0.01437) * \frac{0.3 * 0.62}{1000} * 3600 \quad \text{m.p.h.p.s}$$

$$\{ Fa = 102\, w\, a \}$$

Ib·wt — tons — m.p.h.p.s

- when train accelerates K.E is produced in 2 ways

① Linear motion of the train

② rotation of wheel and motors.

$$K.E_t = K.E_{Linear} + KE_{rotation}$$

$$= \frac{1}{2} \overset{m}{w} V^2 + \sum \frac{I}{2} \omega^2, \quad \omega = V/r$$

$$= \frac{1}{2} \overset{m}{w} V^2 + \frac{I}{2} \sum \left(\frac{V}{r}\right)^2$$

$$= \frac{1}{2} \overset{m}{w} V^2 + \frac{1}{2} V^2 \sum \frac{I}{r^2} \rightarrow m \text{ (rotating mass)}$$

$$= \frac{1}{2} wV^2 + \frac{1}{2} mV^2$$



$$K.E = \frac{1}{2}(w+m)V^2$$

$$\{ K.E = \frac{1}{2} w_e V^2 \}$$

where

$w$ = dead weight

$w_e$ = effective weight or accelerating mass of the train

$I$ = moment of inertia of rotating parts

$m$ = 8 → 15 % of w

* tractive effort to overcome the train resistance.

$$\{ Fr = w \cdot r \} \quad (\text{Ib·wt})$$

$r$ = specific train resistance (Ib·wt/ton)

القوة المقاومة لحركة القطار وتشمل القوى التي تعاكس الحركة

① الاحتكاكات الميكانيكية مثل الاحتكاك (التي تعتمد على كتلة القطار)

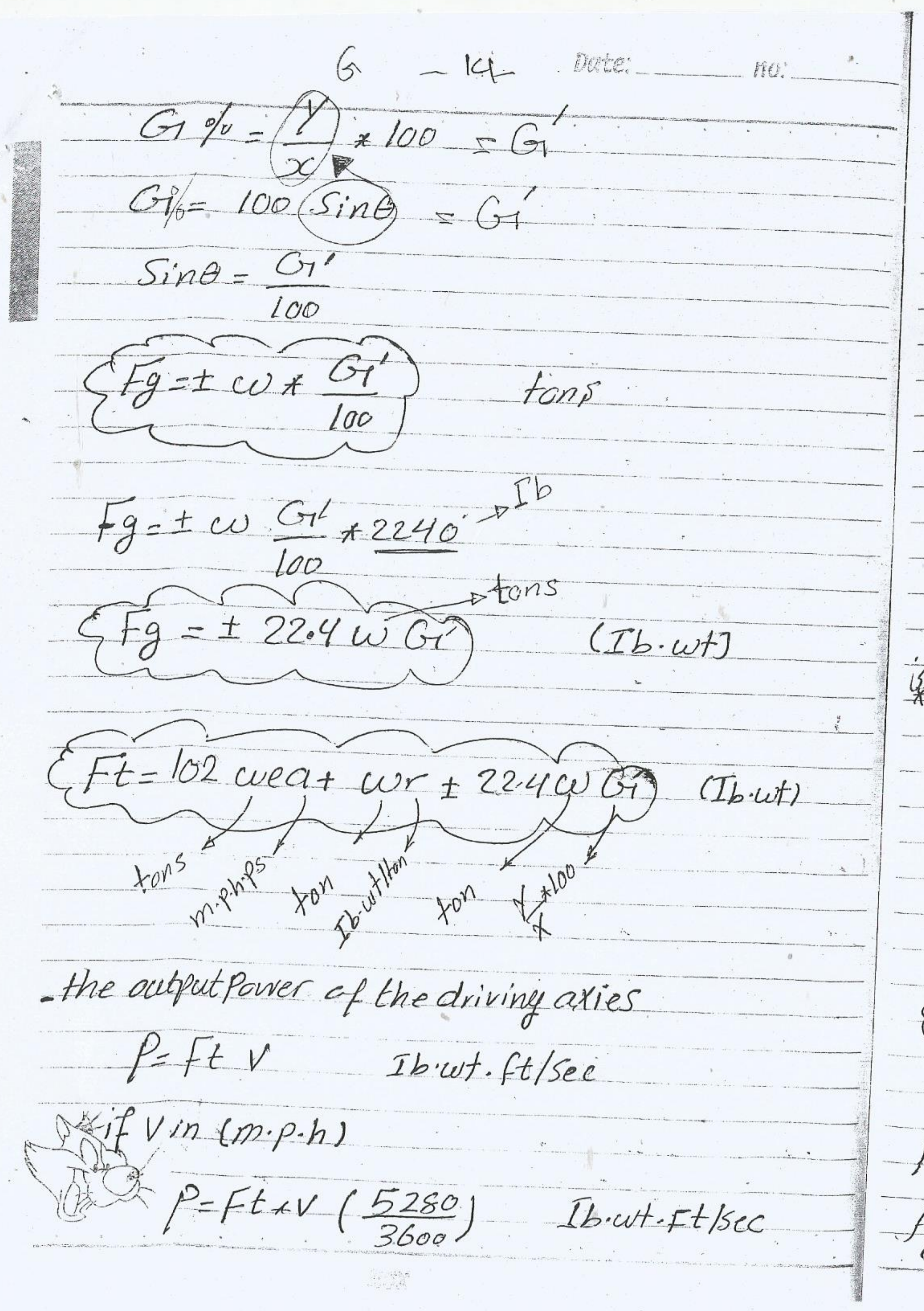
② مقاومة الهواء وهي تتناسب مع مربع سرعة القطار

* tractive effort to overcome the gravity

$$Fg = \pm w \sin\theta$$

if G النسبة المئوية للميل

أو $G = \frac{Y}{X}$ المنحنى





$G\% = \frac{y}{x} * 100 = G'$

$G\% = 100 \sin\theta = G'$

$\sin\theta = \frac{G'}{100}$

$Fg = \pm w * \frac{G'}{100}$ tons

$Fg = \pm w \frac{G'}{100} * 2240$ → Ib

$Fg = \pm 22.4\, w\, G'$ (Ib.wt) (w → tons)

$Ft = 102\, wea + wr \pm 22.4\, w\, G'$ (Ib.wt)

(w → tons, a → m.ph.ps, w → ton, r → Ib.wt/ton, w → ton, $G' \to \frac{y}{x} * 100$)

- the output power of the driving axies

$P = Ft\, V$ Ib.wt.ft/sec

if V in (m.p.h)

$P = Ft * V \left(\frac{5280}{3600}\right)$ Ib.wt.ft/sec



1 h.p = 550 Ib.wt ft/sec

$P = ft.V \left(\frac{5280}{3600 * 550}\right)$ (h.p)

1h.p = 746 w

$P = ft * V \left(\frac{5280 * 746}{3600 * 550 * 1000}\right)$ (Kw)

$P = 0.002\, ft.V$ kw (ft → Ib.wt, V → m.p.h)

* in (SI) system.

$Fa = me.a$ ⇒ Newton

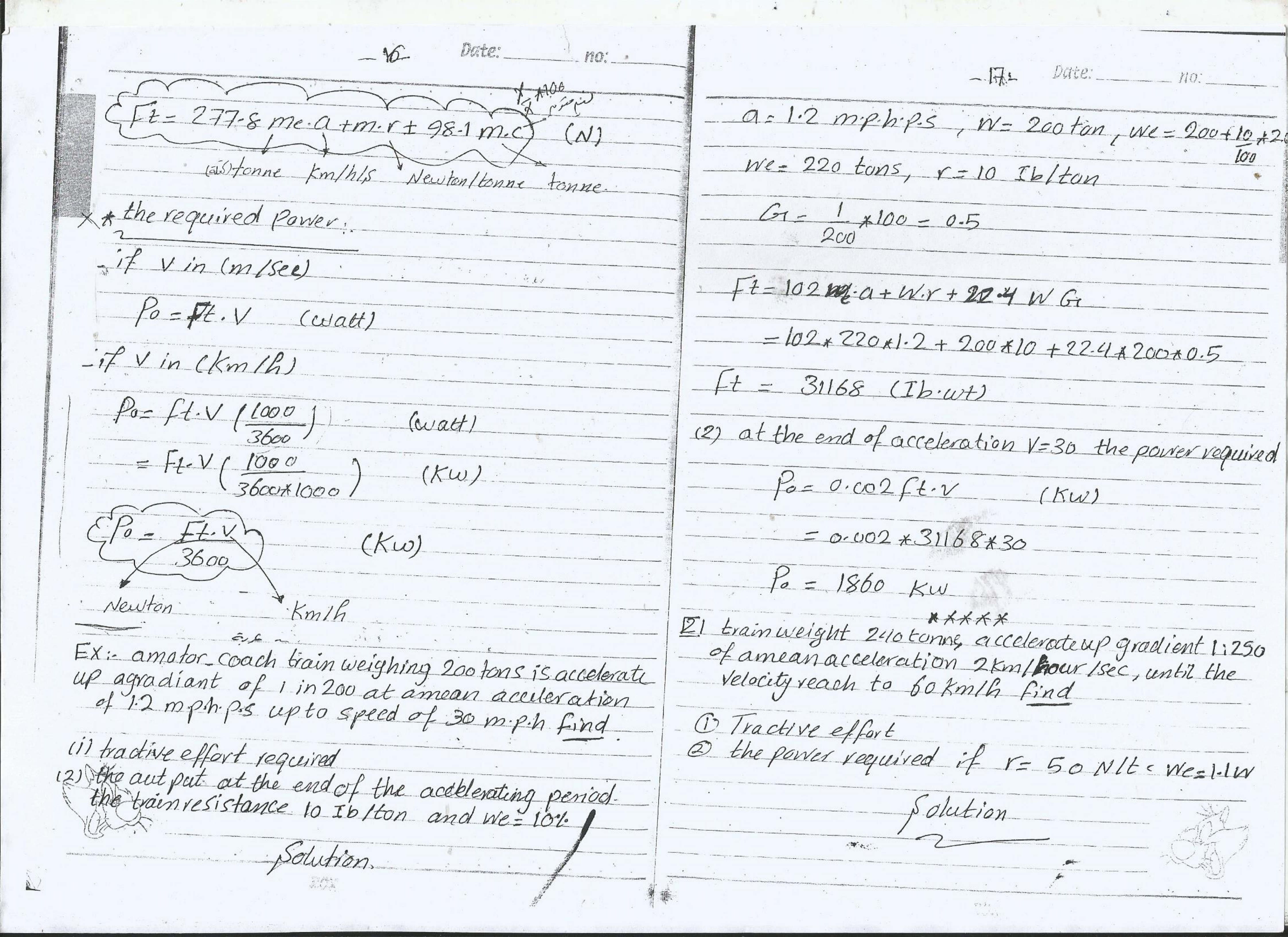
⇒ me → Kg , a → $m/sec^2$

$Fa = me(1000) * a\left(\frac{1000}{3600}\right)$

$fa = 277.8\, me.a$ Newoton (me → tonne, a → Km/h/sec)

$Fr = m(tonne) * r\,(Newton/tonne) = m.r$ (Newton)

$fg = \pm mg \sin\theta = 1000 \times 9.81\, m \frac{c}{100} = 98.1\, m.c$





$$F_t = 277.8\, m_e . a + m . r \pm 98.1\, m . c \quad (N)$$

($m_e$: tonne, $a$: Km/h/s, $r$: Newton/tonne, $m$: tonne)

**the required Power:**

- if V in (m/sec)

$$P_o = F_t . V \quad (watt)$$

- if V in (Km/h)

$$P_o = F_t . V \left(\frac{1000}{3600}\right) \quad (watt)$$

$$= F_t . V \left(\frac{1000}{3600 * 1000}\right) \quad (Kw)$$

$$P_o = \frac{F_t . V}{3600} \quad (Kw)$$

($F_t$: Newton, $V$: Km/h)

Ex:- a motor coach train weighing 200 tons is accelerate up a gradiant of 1 in 200 at a mean acceleration of 1.2 m.p.h.p.s up to speed of 30 m.p.h find

(1) tractive effort required

(2) the out put at the end of the accelerating period. the train resistance 10 Ib/ton and We = 10%

Solution



a = 1.2 m.p.h.p.s , W = 200 ton , $W_e = 200 + \frac{10}{100} * 200$

$W_e$ = 220 tons, r = 10 Ib/ton

$$G = \frac{1}{200} * 100 = 0.5$$

$$F_t = 102\, W_e . a + W . r + 22.4\, W\, G$$

$$= 102 * 220 * 1.2 + 200 * 10 + 22.4 * 200 * 0.5$$

$$F_t = 31168 \quad (Ib.wt)$$

(2) at the end of acceleration V = 30 the power required

$$P_o = 0.002\, F_t . V \quad (Kw)$$

$$= 0.002 * 31168 * 30$$

$$P_o = 1860 \text{ KW}$$

*****

[2] train weight 240 tonne, accelerate up gradient 1:250 of a mean acceleration 2 Km/hour/sec, until the velocity reach to 60 Km/h find

① Tractive effort

② the power required if r = 50 N/t , $W_e = 1.1 W$

Solution

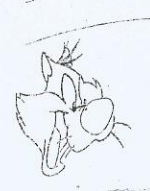
a = 2 Km/h/sec, m = 240 tonne
me = 1.1 * 240 = 264 tonne
r = 50 N/t , $C = \frac{1}{250} * 100 = 0.4\%$

$Ft = 277.8 me.a + m.r + 98.1 m.c$

$= 277.8 * 264 * 2 + 240 * 50 + 98.1 * 240 * 0.4$

$= 168096$ (N)

$Po = \frac{Ft.v}{3600} = \frac{168096 * 60}{3600} = 2802$ Kw





* a train has weighing 250 tonne, run with 4 Motors accelerate up gradient 1:80 and take 20 sec to reach 42 km/sec if Gear ratio 3.5 and $\eta$ = 92% r = 40 N/t , and We = 1.1 W , D = 92 cm
* find the torque produced by each Motor

Solution.

$a = \frac{V}{t} = \frac{42}{20} = 2.1$ Km/h/sec

me = 1.1 * 250 = 275 tonne

$C = \frac{1}{80} * 100 = 1.25\%$

$Ft = 277.8 me.a + m.r + 98.1 m.c$

$Ft = 277.8 * 275 * 2.1 + 250 * 40 + 98.1 * 250 * 1.25$

$= 201054.5$ N

$Ft = \frac{2\eta G_i}{D} Tm$

$201054.5 = 2 * 0.92 * \frac{3.5}{0.92} * Tm$

$Tm = \frac{201054.5 * 0.92}{2 * 0.92 * 3.5} = 28722$ N.m

$Torque/Motor = \frac{28722}{4} = 7180$ N.m.

* train weight 250 tonne move with 4 Motors each produce torque equal 8000 N.m, up gradient 30:1000 if gear ratio 3.5 and $\eta = 90\%$, $r = 50 N/t$, $W_e = 1.1W$ and $D = 90$ cm find ⇒
- time required to reach 80 km/h
- if V = 3000 volte, $\eta = 85\%$ for motor find the current

Solution

$$F_t = 2\eta \frac{G}{D} T_m$$

$$= 2 * 0.9 * \frac{3.5}{0.9} * 4 * 8000 = 224000 \text{ N}$$

$$C = \frac{30}{1000} * 100 = 3\%$$

$$F_t = f_a + f_r + f_g \Rightarrow$$

$$224000 = F_a + 250*50 + 98.1*250*3$$
$$= F_a + 86075$$

$$F_a = 137925 \quad (N)$$

$$F_a = 277.8 m_e * a = 137925$$

$$a = \frac{137925}{277.8 m_e} = \frac{137925}{277.8*1.1*250} = 1.8 \text{ km/h/sec}$$

$$t = \frac{V}{a} = \frac{80}{1.8} = 44.44 \text{ sec}$$





$$\eta_m = \frac{P_o}{P_{in}} \Rightarrow P_{in} = \frac{P_o}{\eta}$$

$$= \frac{F_t . V}{\eta * 3600} \text{ (kW)} = \frac{224000*80}{0.85*3600} = 5856 \text{ kW}$$

$$\text{total Current} = \frac{5856000}{3000} = 1952 \text{ (A)}$$

$$\text{Current / Motor} = 1952/4 = 488 \text{ (A)}$$

* Types of service for people carrying with E.T.

أنواع خدمات نقل الركاب بالجر الكهربائي

1. City [redacted] service. داخل المدينة

حيث تكون التوقف متقارب تقريبا كل 1 كيلومتر ومعدل التسارع والتباطؤ ضروري لتحقيق سرعة عالية متوسطة بين محطات التوقف

2. Suburban city service. ضواحي المدينة

حيث تكون مسافة التوقف ٢-٥ كيلومتر والمسافة الكلية 30-40 km ومعدل التسارع والتباطؤ ضروري

3. main line service. لنقل بين المدن

تكون المسافة طويلة والوقفات قليلة ومعدل التسارع والتباطؤ غير ضروري والسرعات العالية مرغوب فيها

## * Speed time curves:

- there are 2 curves:

[1] speed time curve الأهم

[2] distance-speed curve

- the importance of speed-time curve when we study the motion of train is:

١- يمكن قراءة السرعة مباشرة عند أي لحظة زمنية

٢- ميل المماس يعطي التسارع والتباطؤ عند تلك اللحظة

٣- المساحة المحصورة تحت المنحنى [illegible] تعطي المسافة



* speed-time curve in city service.

* speed-time curve in main line service



١- فترة التسارع الثابت ($0-t_1$): يبذل المحرك فيها عزم الجر اللازم للحفاظ على التسارع الثابت

٢- فترة التسارع على السرعة ($t_1-t_2$): في هذه الفترة يتناقص التسارع تدريجيا حتى تتساوى القوة المتولدة مع المقاومة عندها تصبح السرعة ثابتة ~~[illegible]~~ ($V_2$)

3- فترة الانطلاق الحر ($t_2-t_3$): يسير القطار بسرعة ثابتة بالطاقة التي وصل إليها من نهاية فترة التسارع

٤- فترة الانسياب ($t_3-t_4$): يتم فصل المحركات عن مصدر التغذية فيتحرك بفعل القصور الذاتي فتبدأ السرعة تدريجيا في الانخفاض باستمرار بسبب المقاومة لحركة القطار حتى تبدأ فترة الفرامل للاستفادة من K.E الموجودة من الكتلة الدوارة بدل من إضاعتها في الفرامل

٥- فترة الفرامل ($t_4-t_5$): فرملة القطار باستخدام فرامل كهربائية أو فرامل ميكانيكية.

* The acceleration Period Consist of 2 Part:-

[1] the first part:-

- the motor T-E kept Constant this occure until all the resistance are switched out at speed ($U_1$)
- the tractive effort avaliable for acceleration is (f) and it is the different between motor T-E and train resistance
- the acceleration is this periode is nearly constant

gross (Motor TE)
net T-E
train resist
tractive effort
F
$U_1$
$U_2$ V

[2] the second part:-

- the tractive effort falls rapidly with speed and train resistance increase slowly and then rapidly untile ($V_2$) where motor T.E = train resistance So the net tractive effort available for acceleration is zero

$V_2 \Rightarrow$ max possible speed.

① Crest speed:- max speed attained on the Run

② average speed:- the mean speed from start to stop

$$V = \frac{S}{T} = \text{mile}$$

المسافة بين المحطتين / الزمن الفعلي للسير



③ Schedule speed:- mean speed when stop periode is included

بيدخل زمن التوقف

$$V = \frac{S}{T + T_{stop}}$$

- main line has crest speed 56 m.p.h

* Simplified speed time curves:

speed
amph.s
V
b m.p.h
Tsee
city service quadrilateral
city service trapezoidal
main line service trapezoidal
ta tc tb

- speed time curve for city service can be replaced by quadrilateral or trapezodial fig
- the main line service speed time curve replaced by trapezodial fig.

* for main line service prove that

$$V = \frac{1}{2K}\left[T - \sqrt{T^2 - 14400SK}\right]$$

where

$$K = \frac{1}{2a} + \frac{1}{2b}$$

a: uniform acceleration in m.p.h.p.s

b: uniform braking in m.p.h.p.s

V: crest speed in m.p.h

S: distance to run in (mile)

T: time in sec

*Prove*

- duration of acceleration $(t_a) = V/a$
- " " braking $(t_b) = V/b$
- distance of acc $= \frac{1}{2} V t_a = \frac{1}{2}\frac{V^2}{a}$
- " " braking $= \frac{1}{2} V t_b = \frac{1}{2}\frac{V^2}{b}$
- distance of free run or coasting $= V T_c$

$= V(T - t_a - t_b) = (T - \frac{V}{a} - \frac{V}{b})V$

$= VT - \frac{V^2}{b} - \frac{V^2}{a}$



total distance $= \frac{V^2}{2b} + \frac{V^2}{2a} + VT - \frac{V^2}{a} - \frac{V^2}{b}$

$S' = VT - V^2\left(\frac{1}{2a} + \frac{1}{2b}\right)$   $\frac{mile}{3600} * 3600$

a, b in m.p.h.p.s, V = m.p.h, T in sec

$S' = \frac{mile}{h * sec} * sec$ ← hours لازم نحول

$S' = \frac{mile}{3600 sec} * sec \Rightarrow$ ~~[illegible]~~ $S'$

if we want the distance in miles (S say)

$\frac{S'}{3600} = S$ or: $\boxed{S' = 3600 S}$

نفرض [illegible] 3600× [illegible] لكن [illegible] mile

[illegible] $S'$ [illegible] $\frac{mile}{3600}$ [illegible] $S'$ [illegible] 3600 [illegible] mile/36

$S = S'/3600$ ↓ mile

$3600 S = VT - V^2\left(\frac{1}{2a} + \frac{1}{2b}\right)$

$3600 S = VT - KV^2$

$KV^2 - VT + 3600 S = 0$

$$V = \frac{T \pm \sqrt{T^2 - 4 * 3600 S K}}{2K}$$

$$V = \frac{1}{2K}\left(T \pm \sqrt{T^2 - 14400 S K}\right)$$

(V in m.p.h, T in sec, S in mile)

$T_c = T - t_a - t_b = T - \frac{V}{a} - \frac{V}{b} = T - V\left(\frac{1}{a} + \frac{1}{b}\right)$

$T_c = T - 2KV$

$2KV = T \pm \sqrt{T^2 - 14400K}$

$T_c = T - (T \pm \sqrt{T^2 - 14400KS})$

$T_c = \mp \sqrt{T^2 - 1400SK}$

المطلوب هنا نأخذ الإشارة الموجبة لأنه

لا يوجد زمن سالب.

$T_c = T - 2KV = \pm \sqrt{T^2 - 14400KS}$

+ve

لكي يكون المقدار Tc موجب نأخذ (+)

وعليه كل المقادير الأخرى اشارة سالبة

$2KV = T - \sqrt{T^2 - 14400KS}$

$V = \frac{1}{2K}\left[T - \sqrt{T^2 - 14400KS}\right]$



**EX)** V = 38 m.p.h, maximum runing speed the average distance between stops is 2200 Yd the scheduale speed instanding a station stop of 20 sec is 25 m.p.h find the necessery acceleration allowing a maximum retardolation of 2.5 m.p.h.ps.

$S = 2200\ Yd = 1.25$ miles

$V_{sh} = 25$ m.p.h , $t_{stop} = 20$ sec

time of travel include stop time $= \frac{S}{V} = \frac{1.25}{25} = 0.05$ hr

$T = 3$ minute $= 180$ sec

time of travel $= T - T_{stop} = 180 - 20 = 160$ sec.

$KV^2 - VT + 3600S = 0$

$K = \frac{VT - 3600S}{V^2} = \frac{1}{2a} + \frac{1}{2b}$

$\frac{1}{a} = \frac{2}{V^2}\left(VT - 3600S\right) - \frac{1}{b}$

$\frac{1}{a} = \frac{2}{38^2}\left(38 \times 160 - 3600 \times 1.25\right) - \frac{1}{2.5}$

$1/a = 1.76 \Rightarrow a = 0.57$ m.p.h.ps

*Sheet*

[1] Two stops per mile ⇒ Distance $S = 0.5$ mile

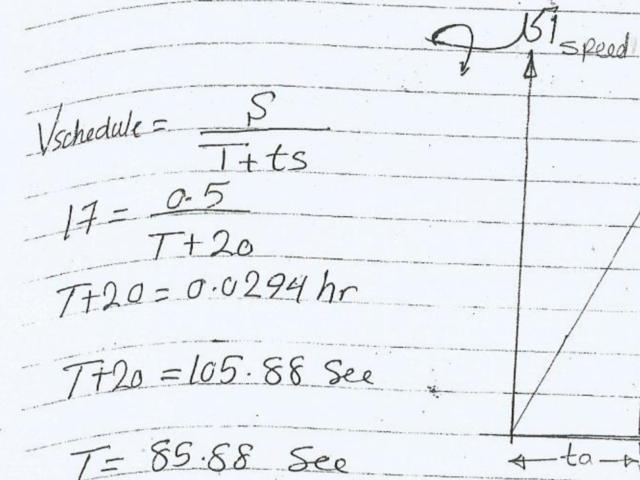
Schedule speed 17 [m.p.h]

Time of stop $t_s = 20$ [sec]

acceleration $= 1.2$ [m.p.h.p.s]

braking retardation $b = 2$ [m.p.h.p.s

* Determine the trapezoidal speed time curve?




$$V_{schedule} = \frac{S}{T + t_s}$$

$$17 = \frac{0.5}{T + 20}$$

$T + 20 = 0.0294$ hr

$T + 20 = 105.88$ sec

$T = 85.88$ sec

$$V = \frac{1}{2K}\left[T - \sqrt{T^2 - 14400 S K}\right]$$

$$K = \frac{1}{2a} + \frac{1}{2b} = \frac{1}{2*1.2} + \frac{1}{2*2} = 0.66$$



$$V = \frac{1}{1.33}\left[85.88 - \sqrt{(85.88)^2 - 14400*0.5*0.66}\right]$$

$V = 26.06$ [m.p.h]

$$t_a = \frac{V}{a} = \frac{26.06}{1.2} = 21.7 \text{ [sec]}$$

$$t_b = \frac{V}{b} = \frac{26.06}{2} = 13 \text{ [sec]}$$

$t_c = T - t_b - t_a = 51$ [sec]

[2] distance between stops = 1 mile

Schedule speed = 25 [m.p.h]

Time of stop $(t_s) = 20$ [sec]

braking retardation $= 2.25$ [m.p.h.p.s]

$$\frac{\text{max speed}}{\text{average speed}} = 1.25$$

* Assuming a trapezoidal speed time curve and Calculate the acceleration.

$V_{sch} = 25$ m.p.h

$$25 = \frac{S}{T + t_s}$$

$$T + 20 = \frac{1}{25} = 0.04 \text{ [hr]}, \quad T = 124 \text{ [sec]}$$

$V_{av} = \frac{\text{Distance of Run}}{\text{time of Run}} = \frac{1}{124} = 0.00806$ M.P.S

$V_{av} = 29.03$ m.p.h

$\frac{V_{max}}{V_{av}} = 1.25 \Rightarrow V_{max} = 1.25 * V_{av}$

$V_{max} = 1.25 * 29.03 = 36.3$ m.p.h

$V_{max} = \frac{1}{2K}\left[T - \sqrt{T^2 - 14400\, S K}\right]$

$36.3 = \frac{1}{2K}\left[124 - \sqrt{(124)^2 - 14400 * 1 * K}\right]$

$72.6K = 124 - \sqrt{15376 - 14400K}$

$(72.6K - 124)^2 = \left(-\sqrt{15376 - 14400K}\right)^2$

$(72.6K)^2 - 2*72.6*124K + 124^2 = 15376 - 14400K$

$5270.76K^2 - 18004.8K + 15376 = 15376 - 14400K$

$5270.76K^2 - 3604.8K = 0$

$K = \frac{3604.8}{5270.76} = 0.683$

$K = \frac{1}{2a} + \frac{1}{2b} = \frac{1}{2a} + \frac{1}{2*2.25}$ (0.22)



$\frac{1}{2a} = K - 0.222 = 0.461$

$2a = 2.169 \Rightarrow a = 1.08$ [m.p.h.p.s]

**3** $V_1 = 25$ m.p.h , $t_a = 20$ sec , $t_c = 40$ [sec]
$T = 70$ sec. (City service)

$b_c = 0.1$ [m.p.h.s]

Determine the distance run from start to stop and the average speed. (Trapezoidal) أو (quadrilateral)

$T = t_a + t_b + t_c = 70$ sec
$t_b = T - t_a - t_c = 70 - 20 - 40 = 10$ sec

$S_T$ = total distance of the Run

$= S_a + S_b + S_c$ ← مساحة شبه المنحرف
$= \frac{1}{2} t_a V_1 + \frac{1}{2} t_b V_2 + \frac{1}{2} t_c (V_2 + V_1)$

$V_2 = V_1 - b_c t_c$ # $b_c = \frac{V_1 - V_2}{t_c} \Rightarrow V_1 - V_2 =$

Slope $= b_c = \frac{V_1 - V_2}{t_c}$

$V_2 = V_1 - b_c t_c$

$V_2 = 25 - 40 * 0.1$
$V_2 = 21$ m.p.h

$S_T = 1/2 * \frac{20}{3600} * 25 + \frac{1}{2}\frac{10}{3600} * 21 + \frac{1}{2} * \frac{400}{3600}(25 + 21)$

$S_T = 0.354$ mile

$V_{av} = \frac{S_T}{T} = \frac{0.354}{70 \text{ sec}} = 18.2$ m.p.h

**41** $S = 1.2$ miles , $V_{sch} = 25$ m.p.h , $t_s = 20$ sec
Coasting retardation = 0.1 m.p.h.s
Braking retardation = 2 m.p.h.s

$V_1 = 38$ m.p.h $= U_{max}$

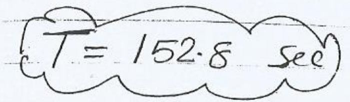
assume quadrilateral speed-time curve and Determine
a) the acceleration
b) duration of coasting period

V, $V_1$, $V_2$, Sa, Sc, Sb, ta, tc, tb

$$V_{sch} = \frac{S}{T+t_s} = 25$$

$$T+20 = \frac{1.2}{25} = 0.048 \text{ hr}$$

$$20+T = 172.8 \text{ [sec]}$$



$T = 152.8$ sec

$$\tan\theta = 0.1 = \frac{U_1 - U_2}{t_c}$$

$$S_T = S_a + S_b + S_c$$

$$= \frac{1}{2} t_a U_1 + \frac{1}{2} t_b U_2 + \frac{1}{2} t_c (U_1 + U_2)$$

but $t_a = \frac{U_1}{a}$ , $t_b = \frac{U_2}{b}$ , $t_c = T - t_a - t_b$

$U_2 = U_1 - 0.1 t_c$ #



$U_2 = b t_b$

$2 t_b = U_1 - 0.1 t_c$ ( $U_1 = 38$ [m.p.h]

$t_b = 19 - 0.05 t_c$

$T = t_a + t_b + t_c$

$t_a = T - t_b - t_c$

$= 152.8 - 19 + 0.05 t_c - t_c$

$t_a = 133.9 - 0.95 t_c$

$$S_T = \left[ \frac{1}{2}(133.9 - 0.95 t_c) * 38 + \frac{1}{2}(19 - 0.05 t_c)(38 - 0.1 t_c) + 0.5 t_c (76 - 0.1 t_c) \right]$$

$$= \frac{1}{7200}\left[ 5810.2 + 36.1 t_c - 0.095 t_c^2 \right]$$

$$8640 = 0.095 t_c^2 + 36.11 t_c - 5810.2$$

$$t_c^2 - 380 t_c + 29787.4 = 0$$

$$t_c = \frac{380 \pm \sqrt{(380)^2 - 4 * 29787.4}}{2*1}$$

$t_c = 190 \pm 79.75$
$t_c = 269.45$ or $110.55$ sec
at $t_c = 110.55$ sec

$t_a = 133.9 - (0.95 \times 11) = 28.45$ [Sec]

$V_2 = 38 - (0.1 \times 111) = 26.9$ [m.p.h]

$a = \frac{V_1}{t_a} = \frac{38}{28.45} = 1.335$ [m.p.h.p.s]

**5** $S = 1$ miles, $V_{avg} = 25$ m.p.h, $a = 1.25$ m.p.h.s

Coasting retardation = 0.1 m.p.h.p.s
Braking retordation = 2 m.p.h.p.s

assume quadrilateral speed time curve and Determine.
1) the duration of acceleration period
2) " " " Coasting "
3) " " " Braking "
4) distance run during these periods.

$V_{avg} = \frac{S_T}{T} = 25$ [m.p.h]

$T = \frac{1}{25} = 0.04$ [hr]

$T = 144$ [Sec]

$U_2 = U_1 - t_c b_c$

$U_2 = U_1 - (T - t_a - t_b) b_c$

$t_a = \frac{U_1}{a}$, $t_b = \frac{U_2}{b}$

$U_2 = U_1 - (T - \frac{U_1}{a} - \frac{U_2}{b}) b_c$



$U_2 = U_1 - (T b_c - \frac{U_1}{a} b_c - \frac{U_2}{b} b_c)$

$U_2 = U_1 - T b_c + \frac{U_1}{a} b_c + \frac{V_2}{b} b_c$

$U_2 (1 - \frac{b_c}{b}) = U_1 (1 + \frac{b_c}{a}) - T b_c$

$U_2 (1 - \frac{0.1}{2}) = U_1 (1 + \frac{0.1}{1.25}) - (144 \times 0.1)$

$0.95 U_2 = 1.08 U_1 - 14.4$

$U_2 = 1.137 U_1 - 15.2$

$S_T = S_a + S_b + S_c$

$= \frac{1}{2} [t_a U_1 + t_c (V_1 + V_2) + t_b U_2]$

$1 = \frac{1}{7200} [\frac{U_1^2}{a} + (U_1 + U_2)(T - \frac{U_1}{a} - \frac{U_2}{b}) + \frac{U_2^2}{b}]$

$7200 = \frac{U_1^2}{a} + U_1 T - \frac{U_1^2}{a} - \frac{U_1 V_2}{b} + V_2 T - \frac{U_1 V_2}{a} - \frac{U_2^2}{b} + \frac{V_2^2}{b}$

$= U_1 T + U_2 T - U_1 U_2 (\frac{1}{a} + \frac{1}{b})$

$= 144 U_1 + 144 (1.137 U_1 - 15.2) - U_1 \times 1.3 \times (1.137 U_1 - 15.2)$

$= 144 U_1 + 163.7 U_1 - 2188.8 - 1.48 V_1^2 + 19.76 U_1$

$7200 = 3275 U_1 - 2188.8 - 1.98 U_1^2$

$0 = 327.5 U_1 - 9388.8 - 1.98 U_1^2$

$U_1^2 - 221.3 U_1 + 634.0 = 0$

$$U_1 = \frac{221.3 \pm \sqrt{(221.3)^2 - 4 * 6343.8}}{2}$$

$$U_1 = \frac{221.3 \pm 153.6}{2}$$

$$U_1 = 110.65 \pm 76.8$$

× $U_1 = 188$ [m.p.h] or $U_1 = 33.85$ [m.p.h]

$$U_2 = (1.137 * 33.85) - 15.2$$

$U_2 = 23.3$ [m.p.h]

$t_a = \frac{U_1}{a} = \frac{33.85}{1.25} = 27$ [sec]

$t_b = \frac{U_2}{b} = \frac{23.3}{2} = 11.63$ [sec]

$t_c = T - t_b - t_a = 144 - 27 - 11.65 = 105.35$ [sec]

$S_a = \frac{1}{2} t_a U_1 = 0.5 * 27 * 33.85 = 0.126$ [mile]

$S_b = \frac{1}{2} t_b U_2 = 0.5 * 11.65 * 23.3 = 0.037$ [mile]

$S_c = S_T - S_a - S_b$

$= 1 - 0.126 - 0.037 = 0.836$ [mile]



## * Calculation of speed time curve.

- the attractive effort available for acceleration

$$F_a = F_T - F_r - F_g$$

$$102\, W_e a = F_T - W r \pm 22.4\, W G_i$$

$$a = \frac{1}{102\, W_e}\left[F_T - W r \pm 22.4\, W G_i\right]$$

$r, F_T$ is a function in speed so if $a$ is a simple function we can integrated it to give ($t$ - $V$) relation as

$$a = \frac{dU}{dt} \Rightarrow t = \int \frac{1}{a}\, dU \quad \#$$

- the above equation gives the time at a certain speed under varying acceleration.

during coasting and braking $a$ and $dU$ are negative.

إذا كانت a صعب تكاملها هنلجأ للطرق البيانية

- $\frac{1}{a}$ is approximatly const up to speed $v_1$
- $\frac{1}{a}$ increase to $\infty$ at speed $v_2$.

$1/a$ ; acc = const ; T.E = " ; I = " ; $V_1$ ; $V_2$ ; speed

علشان نرسم العلاقة بين $\frac{1}{a}$ ، V لـ I لازم
نكون نعرف قيمة الـ a عند اي سرعة.
وعلشان نعرف ايه قيمة t عند اي سرعة ونركز
. acceleration نرسم منحنى (Speed-time)

(Ex) a train has total weight of 116 tons and has four motor each of 275 h.p

| Current (A) | 100 | 200 | 300 | 400 | 500 |
|---|---|---|---|---|---|
| speed (m.p.h) | 51 | 31.4 | 26.4 | 23.9 | 22.1 |
| T.E (Ib.wt)/motor | 390 | 1600 | 2960 | 4330 | 5690 |
| train resistance Ib/ton | 10 | 10 | 10 | 10 | 10 |

- the ratio of effective weight to dead weight is 1.1 , Imean = 425 A per motor , braking retardation is b = 2 m.p.h.ps , S = 0.86 , T = 115 sec , Gi = 0.119 , train resistance during coasting is 10 Ib.wt/ton , find Irms per motor.



« Solution »

- Draw (T.E - Current) , (Speed-Current) curves.
- as shown in fig (1).
- the current not allowed to exceed 425 A (mean current) so that the T.E max /motor is 4650 Ib.wt at speed 23.5 m.p.h. (from drawing).
- $F_g = +22.4\, w\, G_i$

$= 22.4 * 0.119 * 116 = 310$ (Ib.wt)

$r$ = const => $F_r$ = const

- find $F_T$, $F_r$, $F_g$ , $1/a$ against speed.

| speed | 23.5 | 26 | 28 | 30 | 35 | 40 | 45 |
|---|---|---|---|---|---|---|---|
| $F_T$ ($4*F_m$) | 18400 | 12800 | 10000 | 7600 | 5000 | 3400 | 2200 |
| $F_r$ | 1160 | | | | | | |
| $F_g$ | 310 | | | | | | |
| $F_a$ | 16930 | 12374 | 8530 | 6130 | 3530 | 1930 | 730 |
| a | 1.3 | 0.955 | 0.656 | 0.47 | 0.27 | 0.148 | 0.056 |
| 1/a | 0.767 | 1.1 | 1.52 | 2.12 | 3.68 | 6.7 | 17.8 |

to find Ft:-

- from drawing at speed we can find Fmotor then we multiplying $F_m * 4$

to find a:-

$F_a = 102 W_e a$

$a = \frac{F_a}{102 W_e}$

$a = \frac{F_a}{13000}$ (m.p.h.p.s)

- then find $\frac{1}{a}$

- Draw $\frac{1}{a}$ with V.

the acceleration is constant at speed $V_1 = 23.5$

$\left.\frac{1}{a}\right|_{23.5} = 0.767$

- to Draw speed time Curve:-

$a = \frac{dv}{dt}$ , $dt = \frac{1}{a} dv$, $t = \int \frac{1}{a} dv$

عند رسم العلاقة بين V ، $\frac{1}{a}$ فإن المساحة تحت المنحنى تمثل الزمن



at N = 23.5    $t = 23.5 * 0.767 = 18$ sec

at N = 26    $t = 18 + \frac{1}{2}(1.1 + 0.767) * 2.5 = 20.3$ sec

at N = 30    $t = 20.3 + \frac{1}{2}(1.1 + 2.12) * 4 = 26.74$ sec

| speed | 0 | 23.5 | 26 | 30 | 35 | 40 |
|---|---|---|---|---|---|---|
| time | 0 | 18 | 20.3 | 26.74 | 41.24 | 67.19 |

* to Draw braking curve (we draw straight line with slope = 2)

- from T = 115 sec draw line with slope = 2

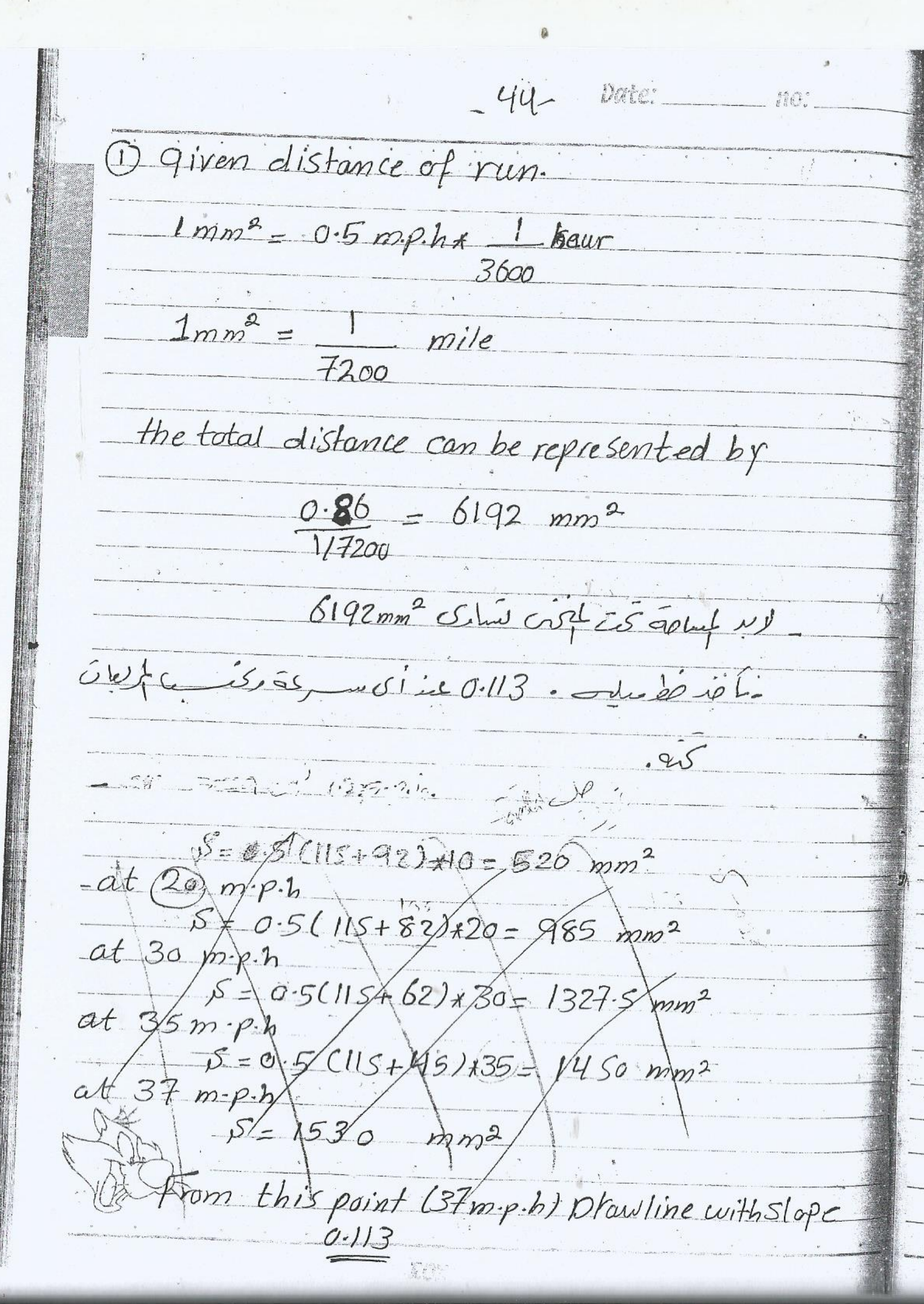
* to Draw coasting line.

- supplying is off so the force is friction force and gravity force.

$F_a = 0$ , $F_T = -F_r - F_g = 102 W_e b_c$

$b_c = \frac{-F_r - F_g}{102 W_e} = \frac{-1160 - 310}{102 * 1.1 * 116} = -0.113$ m.p

- we can not know the end of acceleration and starting of coasting so there are 2 ways:-



① given distance of run.

$1\,mm^2 = 0.5\ m.p.h * \frac{1}{3600}$ hour

$1\,mm^2 = \frac{1}{7200}$ mile

the total distance can be represented by

$\frac{0.86}{1/7200} = 6192\ mm^2$

لابد المساحة تحت المنحنى تساوى $6192\,mm^2$

نأخذ خط ميله 0.113 عند أى سرعة ونحسب المساحة

كده.

$S = 0.5(115+92)*10 = 520\ mm^2$

- at (20) m.p.h

$S = 0.5(115+82)*20 = 985\ mm^2$

at 30 m.p.h

$S = 0.5(115+62)*30 = 1327.5\ mm^2$

at 35 m.p.h

$S = 0.5(115+45)*35 = 1450\ mm^2$

at 37 m.p.h

$S = 1530\ mm^2$

From this point (37 m.p.h) Draw line with slope 0.113



② given $t_b = 15$ sec.

وعليه نرسم خط ميله 0.113 من زمن 100 sec فصاعدا

على coasting line

* Plot (I-t) curve.

at $t > 45$ sec $\Rightarrow I = 0$ . نهاية الـ acceleration .

at $V = V_2 = (36)$ m.p.h   بداية coasting

find I from fig (1)

$I = 175$ (sec)

at $V = V_1 = 23.5$   لأنه I هتكون ثابت لغاية $V_1$

$I = (19)$ (sec)

$I_{rms} = \sqrt{\frac{1}{T}\int i^2 dt}$

$= \sqrt{\frac{1}{115}\left[(425^2 \times 19) + 0.5(45-19)(425^2 + 175^2)\right]}$

$I_{rms} = 230$ A

## Traction motors

- divided to:

1. DC Motors
   - Series
   - Compound
2. AC Motors
   - 1-Ø I.m
   - 3-Ø I.m

* why series or compound motor most used in traction than shunt motor.

1. the series motor or compound have a torque-speed ch/s that show a rapid variation of speed with torque while the shunt motor has a small variation of speed with torque.



2. $N \alpha \frac{1}{r}$ , $N = \frac{V}{r}$ = rotating speed.

at high speed shunt motor may be Run as generator -ve torque produced.



## * Starting and speed control of DC motor.

- speed of dc motor can be varied by:

[1] Varying the field.

a. by tapping on the field.

b. by shunt resistance across it "field weakening"

[2] Varying voltage applied.

a. Series resistance method (notching)

b. Series parallel method

c. metadyne

d. word leanond system (not used in E.T)

(a) Notching:

the Current in Series motor given



$E = V - IR_T$ , $R_T = R_a + R_f + R_{ex}$

$I = \frac{V}{R_T + KN_1}$ , $E = KNI$

at $N = 0 \Rightarrow I_{st} = \frac{V}{R_T}$ where $R_T$ is small so $I_{st}$ is large.

- 48 - Date: ______ no: ______

So external resistance is inserted to limited $I$ and we decrease $R_{ex}$ gradually so until it go out of Circuit the the current is

$$I = \frac{V}{K_1 N + R_a + R_f}$$

- the Current has a min & max value.

at $N = 0$ $\quad I = I_{max} = E/R$

$N = N_1$ $\quad I = I_{min}$

$N = N_2$ $\quad I = I_{max}$ (R reduced)

$N = N_3$ $\quad I = I_{min}$



in this way we divided the current until we reach to full speed.

- disadvantges.
- cupper loss
- * decrease speed
- limitting current
- * advantges.
- easy to use, simple
- reduce starting current, $Pf = 1.0$

- في البداية تكون المقاومة كبيرة في البداية لكي ذلك Limited للتيار ولكن Imax. بعد ذلك سيتزايد سرعة الموتور ويقل التيار إلى Imin يتم إخراج جزء من المقاومة وعليه يزيد التيار إلى Imax بعد ذلك تزداد السرعة فيقل التيار فيتم المقاومة فيزيد التيار حتى يتم إخراج المقاومة بالكامل من الدائرة

- 49 - Date: ______ no: ______

[2] Series - parallel Control (to decrease Copper loss)

- in this method we deal with 2 motor

1. the 2 motor can be started in series with starting resistance until half speed and then the series resistance is zero so $E_1 + E_2 = V$ $\quad (0 \rightarrow N/2)$

2. motor switched into parallel with limitting resistance again until full speed so

$$E_1 = E_2 = V \quad (N/2 \rightarrow N)$$

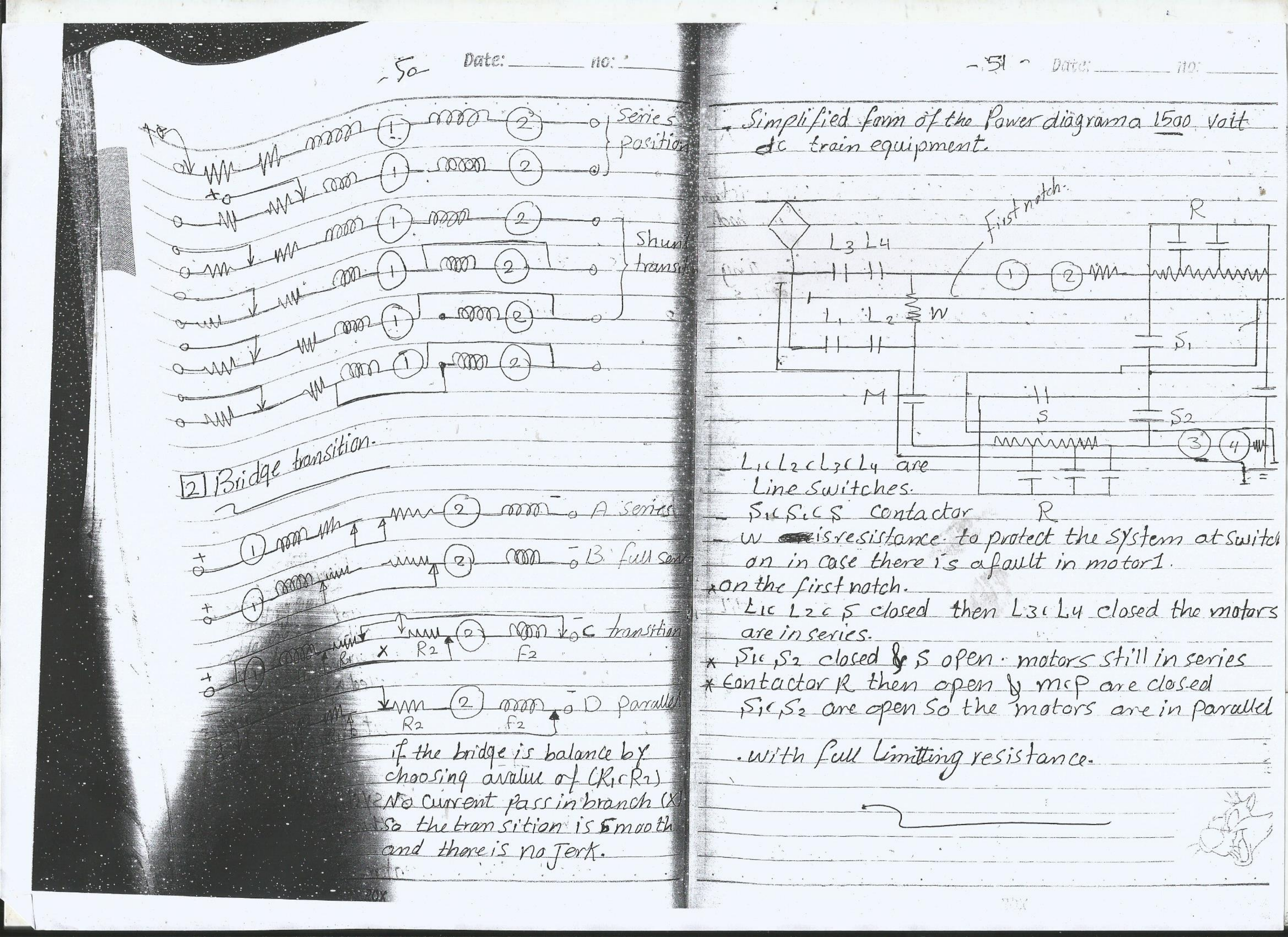
- there are 2 method for transition from series to parallel.

[1] shunt transition:

1. the motor runing at $N/2$ and series resistance is out
2. Some resistance is reinserted
3. one motor is short circuit
4. this motor has one end opened.
5. then this end is connected across so that motors are in parallel.
6. the series resistance is out of circuit.

* disadvantges.

1. there is a Jerk in the system as one motor is shorted and another Jerk when reinserted due to K.E in motor.







## 2 Bridge transition.



if the bridge is balance by choosing avalue of ($R_1$, $R_2$) No current pass in branch (X) So the transition is smooth and there is no Jerk.



- Simplified form of the Power diagram a 1500 volt dc train equipment.



- $L_1$, $L_2$, $L_3$, $L_4$ are Line Switches.
- $S_1$, $S_1$, S contactor R
- W is resistance to protect the system at switch on in case there is a fault in motor1.

* on the first notch.
$L_1$, $L_2$, S closed then $L_3$, $L_4$ closed the motors are in series.

* $S_1$, $S_2$ closed & S open. motors still in series

* Contactor R then open & M, P are closed $S_1$, $S_2$ are open so the motors are in parallel

. with full limitting resistance.

## Energy saved By series parallel control:

- there are 2 cases:

1. motors started in parallel with limiting resistance
2. motors started with series and parallel method.

- in both cases we assume that the series limiting R are continous varied so current in each motors equal to the max value whether in series or parallel so motors produce a constant torque

- neglect armature and field resistance.

| Parallel notching. | Series-parallel |
| --- | --- |
| I → (M), I → (M), 2I | I → (M) (M) → N/2; 2I, I → (M), I → (M) |

- the speed and back emf increase with time until E = V at t = tA

(N/2 → N)

Figure labels (parallel notching): Voltage, C, R, B, VR, Q, P, Eb, B', tP, tA
Figure labels (series-parallel): Voltage and back emf, R, B', B, Q, M, = Eb, tN, tA, t, moto

$E_{input} = \frac{1}{2}\frac{T}{2}V\cdot I + \frac{1}{2}\frac{3}{2}V\cdot\frac{I}{2}$ 2I

$E_{input} = \frac{1}{4}VIT + \frac{3}{4}IVT = VIT$



at $t = tP$

$E_b = QP$

the drop on limiting resistance = QR

$P_{loss} = 2I\,QR$

$E_{loss} = \Delta OCB * 2I$ (volt - time)

$= 2I(0.5VT)$

$E_{loss} = IVT$

input energy to motors =

$= 2I * \Delta OBB'$

$= 2I * (0.5VT)$

$E_{inp} = IVT$ (out)

$\eta_{notch} = \frac{P_{out}}{P_{in}} * 100 = \frac{P_{out}}{P_{out} + P_{loss}}$

$\eta_{notch} = \frac{IVT}{IVT + IVT} = 0.5$

$\eta_{notch} = 50\%$ ✓

∴ $\eta_{s.p} > \eta_{notching}$

at $t = tN$ the motor connected parallel

$E_b = MN$ and drop on R = M

- in series made the losse

$E_{loss} = I * \Delta OCB'$

at $t = tN$ motors switched in parallel so Eloss equal

$E_{loss} = 2I\Delta MB'B$

$E_{loss} = I * \Delta OCB' + 2I\Delta MB'B$

$= I(0.5VT/2) + 2I(\frac{1}{2}\frac{V}{2}T/2)$

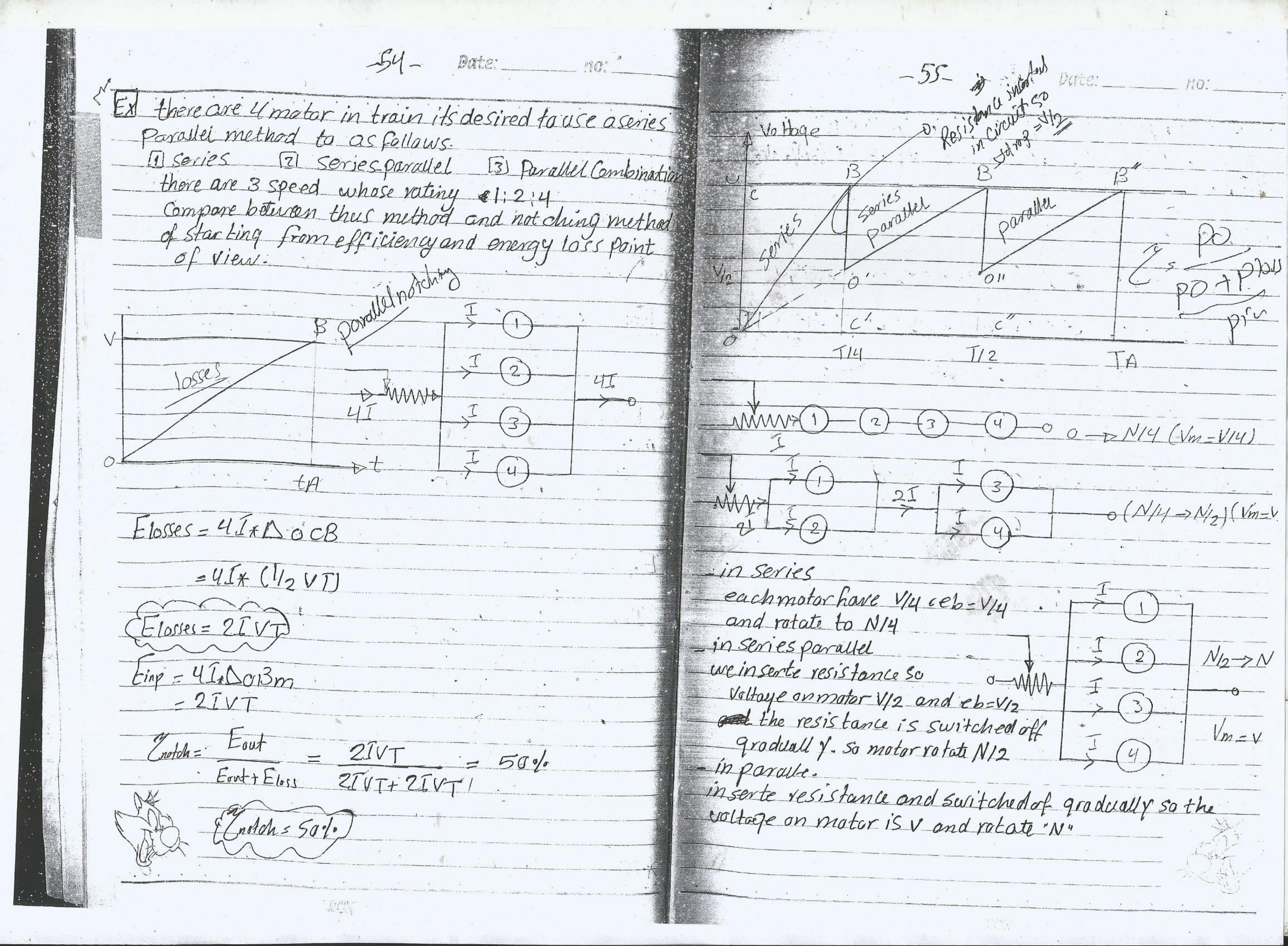
$E_{loss} = 1/2\,VTI$

$E_{loss\ notch} > E_{loss\ (S/P)}$

$\eta_{s.p} = \frac{IVT}{IVT + 1/2\,IVT}$ (Po)

$\eta_{s.p} = 66\ 2/3\ \%$

* Energy wasted in series parallel is half that in notching





Ex there are 4 motor in train its desired to use a series Parallel method to as follows.

1 series  2 series parallel  3 Parallel Combination

there are 3 speed whose rating 1:2:4

Compare between thus method and notching method of starting from efficiency and energy loss point of view.



$E_{losses} = 4I * \Delta\, OCB$

$= 4I * (1/2\, VT)$

$E_{losses} = 2IVT$

$E_{inp} = 4I * \Delta\, OBm$

$= 2IVT$

$\eta_{notch} = \frac{E_{out}}{E_{out} + E_{loss}} = \frac{2IVT}{2IVT + 2IVT} = 50\%$

$\eta_{notch} = 50\%$





- in series
  each motor have V/4 & eb = V/4
  and rotate to N/4
- in series parallel
  we inserte resistance so
  Voltage on motor V/2 and eb = V/2
  the resistance is switched off
  gradually. so motor rotate N/2
- in parallel.
  inserte resistance and switched of gradually so the voltage on motor is V and rotate "N"

$E_{loss} = I\Delta OCB + 2I\Delta O'BB' + 4I\Delta O''BB''$

$= I(0.5VT/4) + 2I(0.5V/2\ T/4) + 4I\{V/2 * T/2 * 1/2\}$

$E_{losses} = 0.75\ IVT$

input energy:

$= I\Delta OBC' + 2I[O'B'C''C'] + 4I[*\text{area } C''O''B''M$

$= I(0.5VT/4) + 2I\left(\frac{V+0.5V}{2} * T/4\right) + 4I\left(\frac{V+0.5V}{2}\right)T/2$

$= \frac{IVT}{8} + \frac{3}{8}IVT + \frac{3}{2}IVT$

$= 2IVT$

$E_{inp} = E_{out}$ of motors = Energy used

$\eta_{s/p} = \frac{E_{out}}{E_{in} + E_{loss}} = \frac{2IVT}{2IVT + 0.75IVT} = 0.73$

$\eta_{s/p} = 73\%$

$\eta_{s/p} > \eta_{notch}$ #

$\frac{E_{loss}}{E_{used}} = \frac{0.75IVT}{2IVT} = 0.375$



* Field weakening or tapped field control:

- using tapping

by tapping field winding to change $I_f$ and so on change flux.

- using shunt resistance

the armature current is const but as $R_{sh}$ change $I_{fsh}$ change and so $I_f$ change to have $I_a$ = const

($I_a$, $I_f$, $R_f$, $I_{sh}$, $R_{sh}$)

**Ex**

The following figures relate to a series wound motors of an electric locomotive.

| Current per motor (A) | 200 | 300 | 400 | 500 |
|---|---|---|---|---|
| train speed (m.p.h) | 41.5 | 33.5 | 28.5 | 28.0 |
| Tractive effort /motor (Ib) | 1300 | 2460 | 3660 | 4870 |

Calculte the value of speed and T.E for the same range armature current when a series field current reduced by 20% by a field diverting resistance.

$I_{f\,new} = 0.8\ I_{f\,old}$ (I, 0.8I, 0.2I, $R_{sh}$)

$V = E + I_a r_a$

$e = E = K\phi N$ neglect volte drop

if supply volte is const $N \propto \frac{1}{\phi}$, $\phi \propto I_f$

Date: ______ no: ______

the relation between speed and current it isnot Linear.

$I_a$ = const  $I_a = I_f\downarrow + I_{fsh}\uparrow$ = cons

at $I_a = 500A \Rightarrow I_{fnew} = 0.8 * 500 = 400\ A \Rightarrow N = 28.5$

at $I_a = 400A \Rightarrow I_{fnew} = 0.8 * 400 = 320A \Rightarrow N = 32$

at $I_a = 300A \Rightarrow I_{fnew} = 0.8 * 300 = 240A \Rightarrow N = 38$

at $I_a = 200A \Rightarrow I_{fnew} = 0.8 * 200 = 160A \Rightarrow N = 45.$

$N \alpha \frac{1}{I_f}$

مع التغيير نقص قيم السرعة عند تغير
تماماً يقلل (If)

* $T.E \alpha I\phi$ , $\phi \alpha \frac{1}{N} \Rightarrow T.E \alpha \frac{I}{N}$ at const E

- relation between T.E and Ia from curve is nearly Linear So

$$T.E_{new} = T.E_{old} * \frac{N_{old}}{N_{new}}$$

at Ia = 500A

$$T.E|_{500} = 4870 * \frac{28}{28.5} = 4784.56 \downarrow (ib)$$

at Ia = 400A

$$T.E|_{400} = 3660 * \frac{28.5}{32} = 3260 \downarrow ib$$

لان السرعة زادت

at Ia = 300A

$$T.E|_{300} = 2460 * \frac{33.5}{38} = 2168 \downarrow (ib)$$

at Ia = 200 A ⇒



$$T.E|_{200} = 1300 * \frac{41.5}{45} = 1198.9 \downarrow (ib)$$

- Draw the new Curves.

| Current per motor (A) | 200 | 300 | 400 | 500 |
|---|---|---|---|---|
| trainspeed (m.p.h) | 45 | 38 | 32 | 28.5 |
| tractive effort permotor | 1198.9 | 2168 | 3260 | 4784.56 |

* find an expression for specific energy consumption (S.E.C)

$$S.E.C = \frac{\text{energy consumption (w.hr)}}{W.S}$$

W ⇒ dead weight , S ⇒ length of train

$$S.E.C \text{ for acceleration} = \frac{1/2\ P_a\ t_a}{W.S}$$

$$S.E.C\,A = \frac{1/2\,(0.002) * 102 W_e \alpha V\ V/\alpha}{W.S} \quad \text{Kw.sec / ton mile}$$

$$= 0.102 \frac{W_e V^2}{W.S} \quad \text{Kw.sec / ton mile}$$

$$S.E.C\,A = 0.028 \frac{W_e V^2}{W.S} \quad \text{w.h / ton mile}$$

Energy consumption for acceleration $= \frac{1}{2}$ Pata

$= \frac{1}{2}$ Pata $= 0.028\, we\, V^2$ (w.h)

[2] S.E.C for overcome train resistance.

$$S.C.CR = \frac{2 F_r S'}{W S} = \frac{2 W r S'}{W S}$$

$$SECR = 2r \frac{S'}{S} \quad (w.h / ton.mile.)$$

where

$S' = \frac{1}{2} t_a V_m + t_c V_m$ → free runing

$S' = \frac{1}{2} t_a V_m$ → without free runing

energy consumption for resistance $= 2 F_r S'$ (w.h)

[3] SECG (energy consumption to over come gradiant gravity)

$$S.E.CG = \frac{2 F_g S'}{W S}$$

$$= \frac{\pm 2 * 22.4\, W G' S'}{W S}$$

$$SECG = \pm 44.8 \frac{G' S'}{S}$$



$G' = 100 \sin\theta$

- energy consumption for gradiant gravity

$= 2 F_g S'$ (w.h)

Sheet (1)

(6) 2 stations, 1 mile part, $S = 1.0$ mile, $V_{av} = 25$ m.p.h u, $= 27.5$ m.p.h d

died weight = 210 tons
acceleration = 1.2575 m.p.h.p.s
braking retardation = 2 m.p.h.p.s
net T.E = 30000 Ib up
" " = 47000 Ib down
r = 12 Ib
we = 1.1 w

- assume both direction made to trapezoidal speed time curve and determine without free Run.

«Solution»

Specific energy output = specific energy consumption

S.E.C = energy need to accelerate train
+ " " " over come " resistance
+ " " " " " gravity

| acceleration | retardation |
| --- | --- |
| $f_t = f_a + f_r + f_g$ up → aup | $f_t = f_a - f_r - f_g$ up → bup |
| $f_t = f_a + f_r - f_g$ down → ado | $f_t = f_a - f_r + f_g$ down → bdo |

① S.E need to accelerate the train

$$S.E.C.A = \frac{1/2 \, Pa \, ta}{w.s}$$

$$= \frac{1}{2} \frac{0.002 \, fa \, v \, V/a}{w.s}$$

$$S.E.C.A = 0.028 \frac{We V^2}{w.s}$$ w.h/ton mile

② S.E need to overcome the train resistance

$$S.E.C.R = \frac{2 fr S'}{w.S} = \frac{2 r S'}{S}$$ # w.h/tonmile

$S' = 0.5 \, ta \, Vm + tc \, Vm$ ✓

$S' = 0.5 \, ta \, Vm$

③ S.E need to overcome gradiant gravity

$$S.E.C.G = \frac{2 fg S'}{w.S} = \frac{\pm 2 * 22.4 W G' S'}{w.S}$$

$$S.E.C.G = \pm 44.8 \frac{G' S'}{S}$$ #

acceleration $a = 1.2575$

$fa = ft - fr - fg$ →0

$fa = ft - fr = 30000$

braking $b = 2$ m.p.h.p

$fb = ft + fr - fg$ →0 → 470000



1) For acceleration the train

$fa = ft - fg - fr$

$102 \, we \, dup = ft - fg - fr$

$$dup = \frac{ft - fg - fr}{102 We} = \frac{30000 - (22.4 * 210 * \frac{100}{80})}{102 * 231}$$

$dup = 1.02$ [m.p.h.p.s]

$$\alpha down = \frac{ft + fr + fg}{102 We} = \frac{30000 + (22.4 * 210 * \frac{100}{80})}{102 * 231}$$

$\alpha down = 1.523$ m.p.h.p.s

$fb = fT - fr - fg$

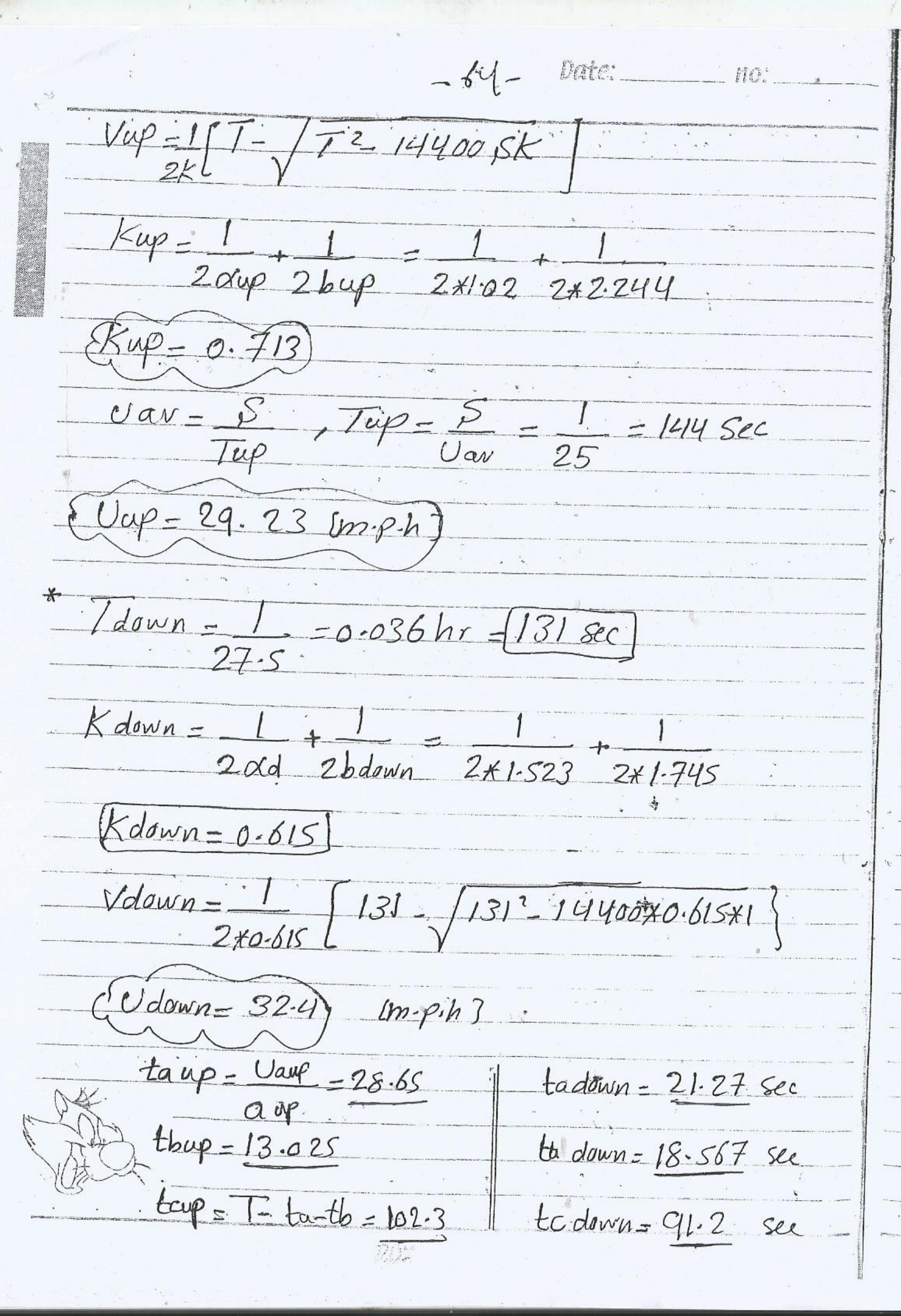
$$b = \frac{ft + fr - fg}{102 we}$$

$$bup = \frac{ft + fr + fg}{102 we} = \frac{47000 + (22.4 * 210 * 100/80)}{102 * 231}$$

$bup = 2.244$ m.p.h.s

$$bdown = \frac{ft + fr - fg}{102 We} = \frac{47000 - (22.4 * 210 * 100/80)}{102 * 231}$$

$bdown = 1.745$ m.p.h.p.s





$V_{up} = \frac{1}{2K}\left[T - \sqrt{T^2 - 14400\,SK}\right]$

$K_{up} = \frac{1}{2\alpha_{up}} + \frac{1}{2b_{up}} = \frac{1}{2*1.02} + \frac{1}{2*2.244}$

$K_{up} = 0.713$

$U_{av} = \frac{S}{T_{up}}$ , $T_{up} = \frac{S}{U_{av}} = \frac{1}{25} = 144$ sec

$U_{ap} = 29.23$ (m.p.h)

* $T_{down} = \frac{1}{27.5} = 0.036$ hr $= 131$ sec

$K_{down} = \frac{1}{2\alpha_d} + \frac{1}{2b_{down}} = \frac{1}{2*1.523} + \frac{1}{2*1.745}$

$K_{down} = 0.615$

$V_{down} = \frac{1}{2*0.615}\left[131 - \sqrt{131^2 - 14400*0.615*1}\right]$

$U_{down} = 32.4$ (m.p.h)

| | |
|---|---|
| $t_{a\,up} = \frac{U_{avp}}{a_{up}} = 28.65$ | $t_{a\,down} = 21.27$ sec |
| $t_{b\,up} = 13.025$ | $t_{b\,down} = 18.567$ sec |
| $t_{c\,up} = T - t_a - t_b = 102.3$ | $t_{c\,down} = 91.2$ sec |



* for up gradiant direction

$S.E.C.A = 0.028\frac{W_e V^2}{W.S} = 0.028 * \frac{231*29.23^2}{210}$

$S.E.C.A = 26.3$ w.h/ton mile

$S.E.C.r = \frac{2rS'}{S} = \frac{2r*(1/2\, t_a V)}{S}$ ; $S' = \frac{1}{2}\frac{29.23^2}{3600*1.02} = 0.11$ Mile

$= \frac{2*12*28.65*29.23}{2*3600} = 2.8$ w.h/tonmile

$S.E.C.g = +44.8\frac{G'S'}{S} = 44.8 * \frac{100}{80} * 0.5 * \frac{28.65*29.2}{3600}$

$= 6.5$ w.h/ton mile

$S.E.C = 6.5 + 2.8 + 26.3 = 35.6$ w.h/ton mile

* for down gradiant direction

$S.E.C.A = 0.028\frac{W_e V^2}{W.S} = 32.3$ w.h/ton mile

$S.E.C.r = \frac{2rS'}{S} = 2.3$ w.h/tonmile ($S' \to 0.0957$ Mile)

$S.E.C.g = \ominus 44.8\frac{G'S'}{S} = \ominus 5.36$ w.h/tonmile

$S.E.C = 29.2$ w.h/ton mile

7 $W = 250$ ton, $S = 1.25$ mile, $V_{av} = 32$ m.p.h
$a = 1.25$, $b = 2.3$, $r = 12$ Ib
$W_e = 1.1 * 250 = 275$ ton, mainline service.
- assume trapezoidal speed-time curve.
Calculate the energy consumption for the run.

↻ حل

$S.E.C = S.E.C_a + S.E.C_r + S.E.C_g$

- $S.E.C_a = 0.028 \frac{W_e V^2}{W . S}$

$V_{av} \Rightarrow \frac{S}{T} \Rightarrow T = \frac{S}{V_{av}} = \frac{1.25}{32} = 140.6$ sec

$K = \frac{1}{2a} + \frac{1}{2b} = \frac{1}{2*1.25} + \frac{1}{2*2.3} = 0.617$

$V = \frac{1}{2k}\left[T - \sqrt{T^2 - 14400\, S k}\right]$

$= \frac{1}{2*0.617}\left(144 - \sqrt{144^2 - 14400*1.25*0.617}\right)$

$V = 38.51$ (m.p.h)

$S.E.C_a = 0.028 \frac{275*38.51^2}{250*1.25} = 36.56$ w.h/tonmile

$S.E.C_r = \frac{2 r S'}{S} = \frac{2*12*(1/2\, t_a V)}{S}$ $*WS$

$t_c = T - t_a - t_b = T - \frac{V_m}{a} - \frac{V_m}{b}$

(margin notes:)
$0.1648$
$S' = \frac{1}{2}\frac{30.48*38.51}{3600}$
$t_a = \frac{V_m}{a} = 30.48$
$t_b = \frac{V_m}{b} = 16.58$
$t_c = 93.56$
$S' = 1.151$
$S' = \frac{1}{2}\frac{t_a V_m}{3600} + t_c V_m$
$t_c = 140.6 - \frac{V_m}{a} - \frac{V_m}{b}$ (93)
$55.35$
mile $= 1.159$ $S'$
$t_c V_M$
$S.E.C_r = 22.25$ w.h/tonmile



$S.E.C_r = \frac{\frac{1}{2}(29.76*37.2)*\frac{29}{3600}}{1.25} = 22.25$ w.h/tonmile

$S.E.C_t = 22.25 + 36.56 = 58.81$ (w.h/tonmile)

energy consumption $= 58.81 * W * S *$

$E.C = 58.81 * 250 * 1.25 = 18378.2$ w.h

12 given $S = 1.2$ mile, $W = 200$ ton
$V_{sch} = 25$ m.p.h, $W_e = 220$ ton
$t_s = 20$ sec, $r = 10$ Ib/ton
$b_c = 0.1$, $b = 2$
$V_1 = 38$ m.p.h
- assume quadrilateral speed-time curve
- required:
1- S.E output for the run
2- the energy disspated during coasting
3- " " " brakes
4- mean train resistance during coasting.

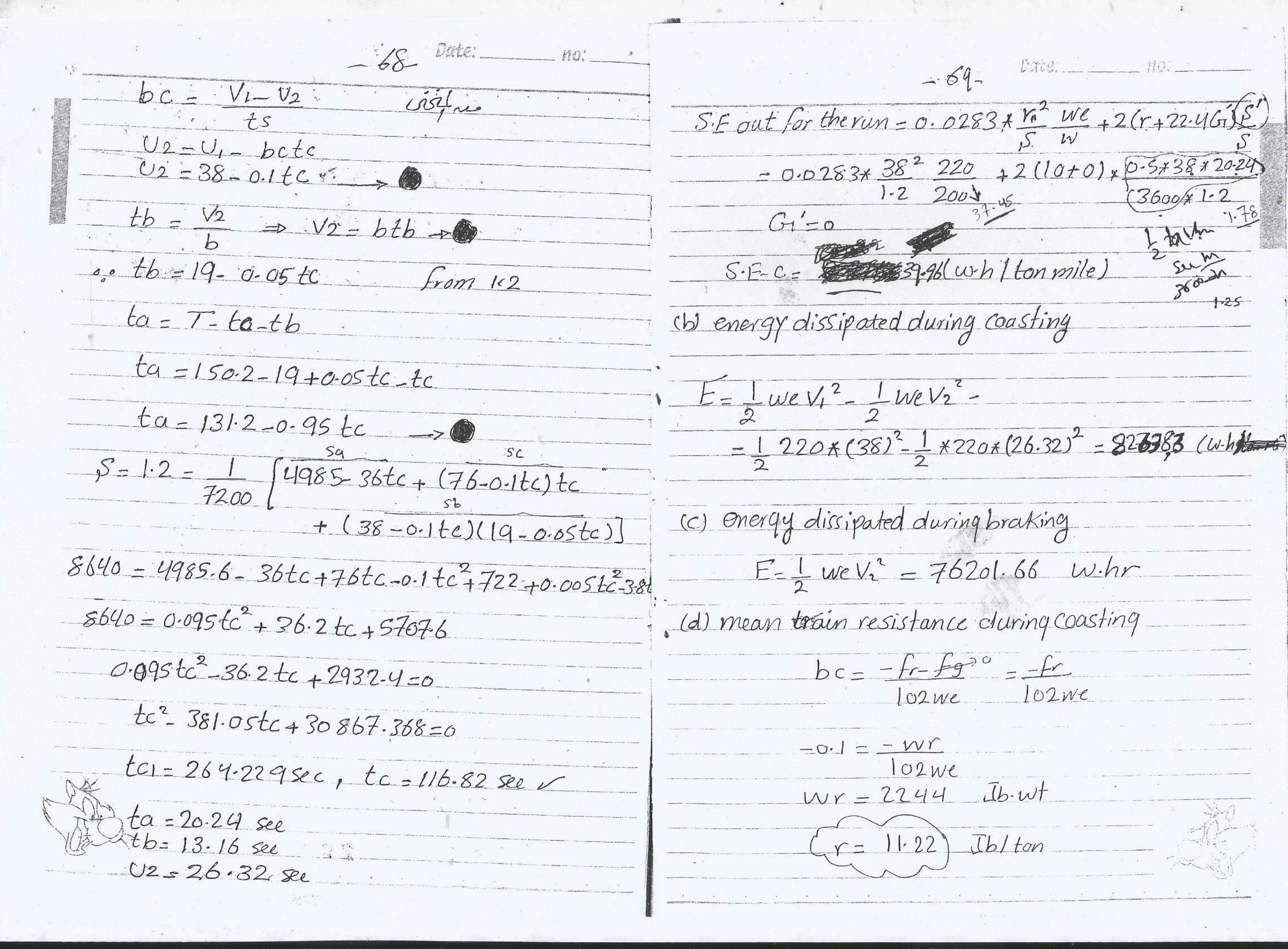
→ حل

$V_{sch} = \frac{S}{T + t_{stop}}$

$T + t_s = \frac{S}{V_{sch}} = \frac{1.2}{25}$
$= 172.8$ sec

$T = 172.8 - 20 = 152.8$ sec

(sketch: speed-time curve, axis labels $V_1$, $V_2$, 115 sec)





$bc = \frac{V_1 - V_2}{ts}$ مثال 1

$U_2 = U_1 - bc\,tc$

$U_2 = 38 - 0.1tc \rightarrow$

$tb = \frac{V_2}{b} \Rightarrow V_2 = b\,tb \rightarrow$

$\therefore tb = 19 - 0.05tc$ from K2

$ta = T - tc - tb$

$ta = 150.2 - 19 + 0.05tc - tc$

$ta = 131.2 - 0.95tc \rightarrow$

$S = 1.2 = \frac{1}{7200}\Big[\underbrace{4985 - 36tc}_{sa} + \underbrace{(76 - 0.1tc)tc}_{sc} + \underbrace{(38 - 0.1tc)(19 - 0.05tc)}_{sb}\Big]$

$8640 = 4985.6 - 36tc + 76tc - 0.1tc^2 + 722 + 0.005tc^2 - 3.8t$

$8640 = 0.095tc^2 + 36.2tc + 5707.6$

$0.095tc^2 - 36.2tc + 2932.4 = 0$

$tc^2 - 381.05tc + 30867.368 = 0$

$tc_1 = 264.229$ sec, $tc = 116.82$ sec ✓

$ta = 20.24$ sec

$tb = 13.16$ sec

$U_2 = 26.32$ sec



S.F out for the run $= 0.0283 * \frac{V_1^2}{S}\frac{We}{W} + 2(r + 22.4G_1')\frac{S'}{S}$

$= 0.0283 * \frac{38^2}{1.2}\frac{220}{200} + 2(10+0) * \frac{0.5 * 38 * 20.24}{3600 * 1.2}$

37.45    1.78

$G_1' = 0$

[redacted]

S.F.C = [redacted] 39.96 (w.h / ton mile)

$\frac{1}{2}$ ta Vm, sec hr, 3600, 1.25

(b) energy dissipated during coasting

$E = \frac{1}{2} We V_1^2 - \frac{1}{2} We V_2^2$

$= \frac{1}{2} 220 * (38)^2 - \frac{1}{2} * 220 * (26.32)^2 = 82383$ (w.h)

(c) energy dissipated during braking

$E = \frac{1}{2} We V_2^2 = 76201.66$ w.hr

(d) mean train resistance during coasting

$bc = \frac{-fr - fg^{\,0}}{102We} = \frac{-fr}{102We}$

$-0.1 = \frac{-Wr}{102We}$

$Wr = 2244$ lb.wt

$r = 11.22$ lb/ton

13 $W = 200$ ton, gross T.E $= 25000$ Ib, $S = 0.8$ mile
$T = 120$ sec, up gradiant, $r = 10$, $W_e = 1.1W$
$b = 2.2$

- required
  - Determine the maximum speed attained
  - energy supplied to the driving wheels.

$$f_a = f_t - f_r - f_g$$

$$102 W_e a = f_t - f_r - f_g$$

$$a = \frac{f_t - Wr - 22.4 W G'}{102 W_e}$$

$V_m$ 120sec

$f_t \Rightarrow$ gross tractive effort $= 25000$ Ib

$f_r = Wr = 200 * 10 = 2000$ Ib.wt
$f_g = 22.4 W G' = 22.4 * 200 * \frac{100}{100} = 4480$ Ib.wt

$$K = \frac{1}{2a} + \frac{1}{2b} = \frac{1}{2*0.825} + \frac{1}{2*2.2}$$

$K = 0.833$

$$V = \frac{1}{2K} * \left[ T - \sqrt{T^2 - 14400 * S * K} \right]$$

$$V = \frac{1}{2*0.833} \left[ 120 - \sqrt{120^2 - 14400 * 0.8 * 0.833} \right]$$

$V_{max} = 30.426$ mph



$$SEC = 0.028 \frac{V^2}{S} \frac{W_e}{W} + 2(r + 22.4 G') S'/S$$

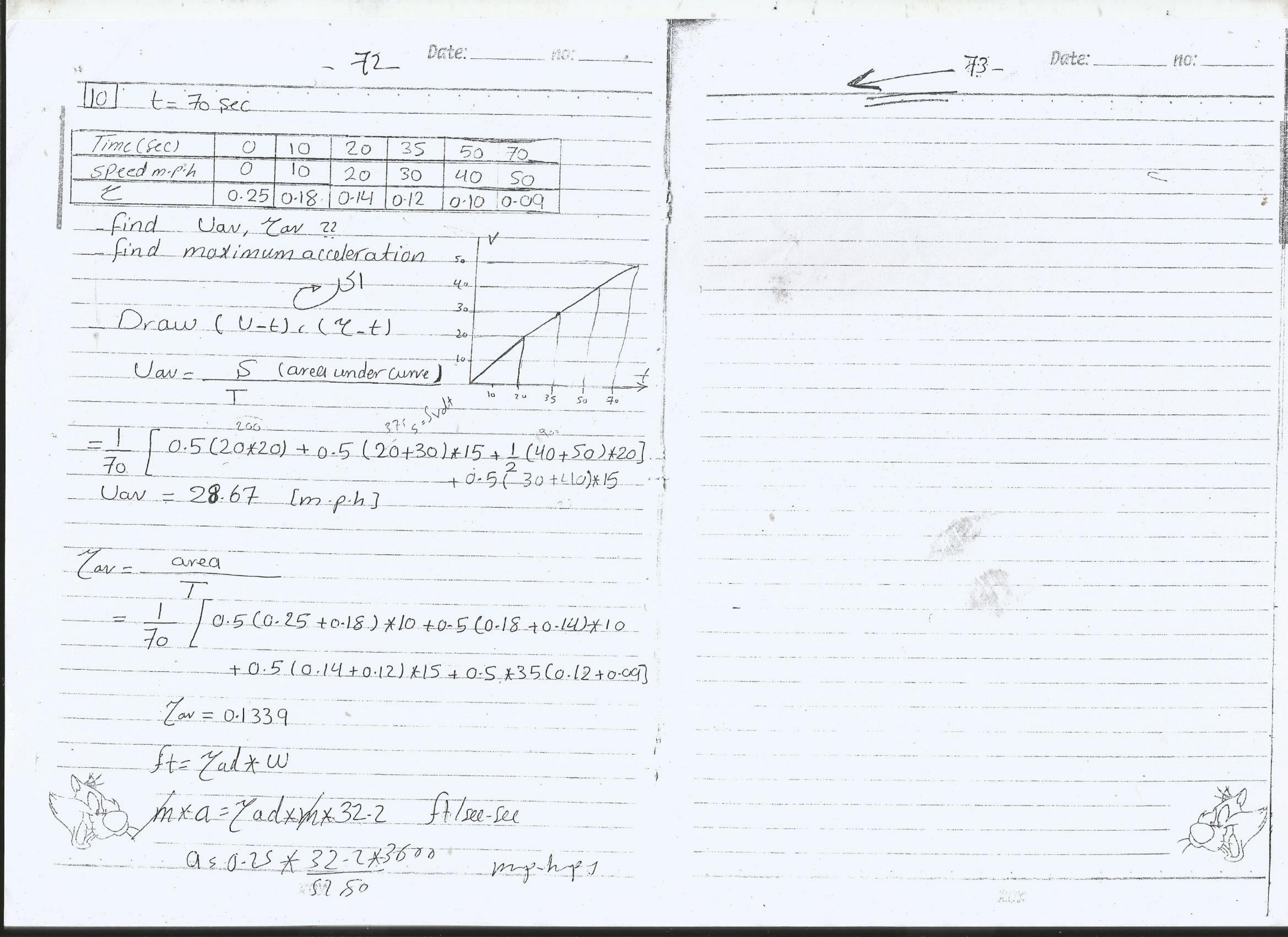
$$SEC = 0.0283 * \frac{(30.426)^2}{0.8} * \frac{220}{200} + 2(10 + 22.4*1) \frac{S'}{S}$$

$$S' = \frac{1}{2} t_a V_m = \frac{1}{2} \frac{V_m^2}{a} = \frac{561.055}{3600} \text{ mile} = 0.155$$

S.E.C $=$ ~~...~~ $48.81$ (w.h/mile ton)

energy supplied to driving wheel $=$ S.EC $* W S$

$=$ ~~...~~ wh $7808.0$ wh





[10] $t = 70$ sec

| Time (sec) | 0 | 10 | 20 | 35 | 50 | 70 |
|---|---|---|---|---|---|---|
| speed m.p.h | 0 | 10 | 20 | 30 | 40 | 50 |
| $\tau$ | 0.25 | 0.18 | 0.14 | 0.12 | 0.10 | 0.09 |

- find $U_{av}$, $\tau_{av}$ ??
- find maximum acceleration

اكل

- Draw $(U-t)$ & $(\tau-t)$



$U_{av} = \frac{S}{T}$ (area under curve)

200   375 $S = \int v\,dt$   900

$= \frac{1}{70}\left[0.5(20*20) + 0.5(20+30)*15 + \frac{1}{2}(40+50)*20\right]$
$+ 0.5(30+40)*15$

$U_{av} = 28.67$ [m.p.h]

$\tau_{av} = \frac{\text{area}}{T}$

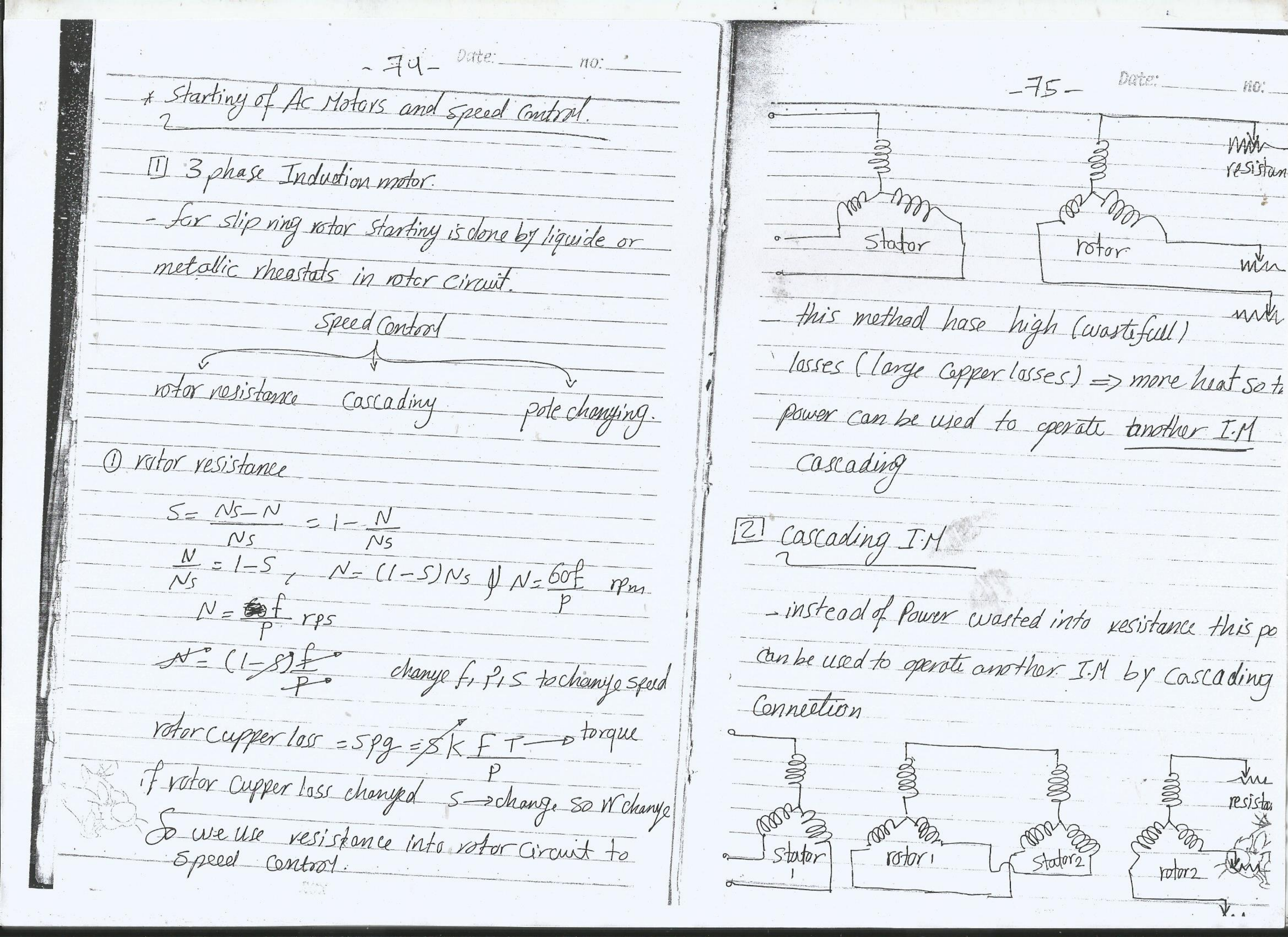
$= \frac{1}{70}\left[0.5(0.25+0.18)*10 + 0.5(0.18+0.14)*10\right.$
$\left. + 0.5(0.14+0.12)*15 + 0.5*35(0.12+0.09)\right]$

$\tau_{av} = 0.1339$

$F_t = \tau_{ad} * W$

$m*a = \tau_{ad}*m*32.2$ ft/sec-sec

$a = 0.25 * \frac{32.2*3600}{5280}$ m.p.h.p.s





* Starting of Ac Motors and speed Control.

[1] 3 phase Induction motor.

- for slip ring rotor Starting is done by liquide or metallic rheostats in rotor circuit.

Speed Control
- rotor resistance
- Cascading
- pole changing.

① rotor resistance

$$S = \frac{N_s - N}{N_s} = 1 - \frac{N}{N_s}$$

$$\frac{N}{N_s} = 1 - S \, , \quad N = (1-S)N_s \quad \& \quad N = \frac{60f}{P} \text{ rpm}$$

$$N = \frac{f}{P} \text{ rps}$$

$$N = (1-S)\frac{f}{P}$$ change f, P, S to change speed

rotor cupper loss $= S P_g = S K \frac{f}{P} T$ → torque

if rotor cupper loss changed S → change so N change

So we use resistance into rotor circuit to Speed control.





- this method hase high (wastefull) losses (large copper losses) ⇒ more heat so the power can be used to operate another I.M Cascading

[2] Cascading I.M

- instead of Power wasted into resistance this power can be used to operate another I.M by cascading Connection

- disadvantages

1- low power factor of Combination

2- require 2 3phase I.m

* the power is taken by a slip ring of the first motor to drive the second motor (SPg).

the reheostat in the second motor enable speed regulation up to the cascade Synchronous Speed

$P_1 = SP_2$ Pairs of poles

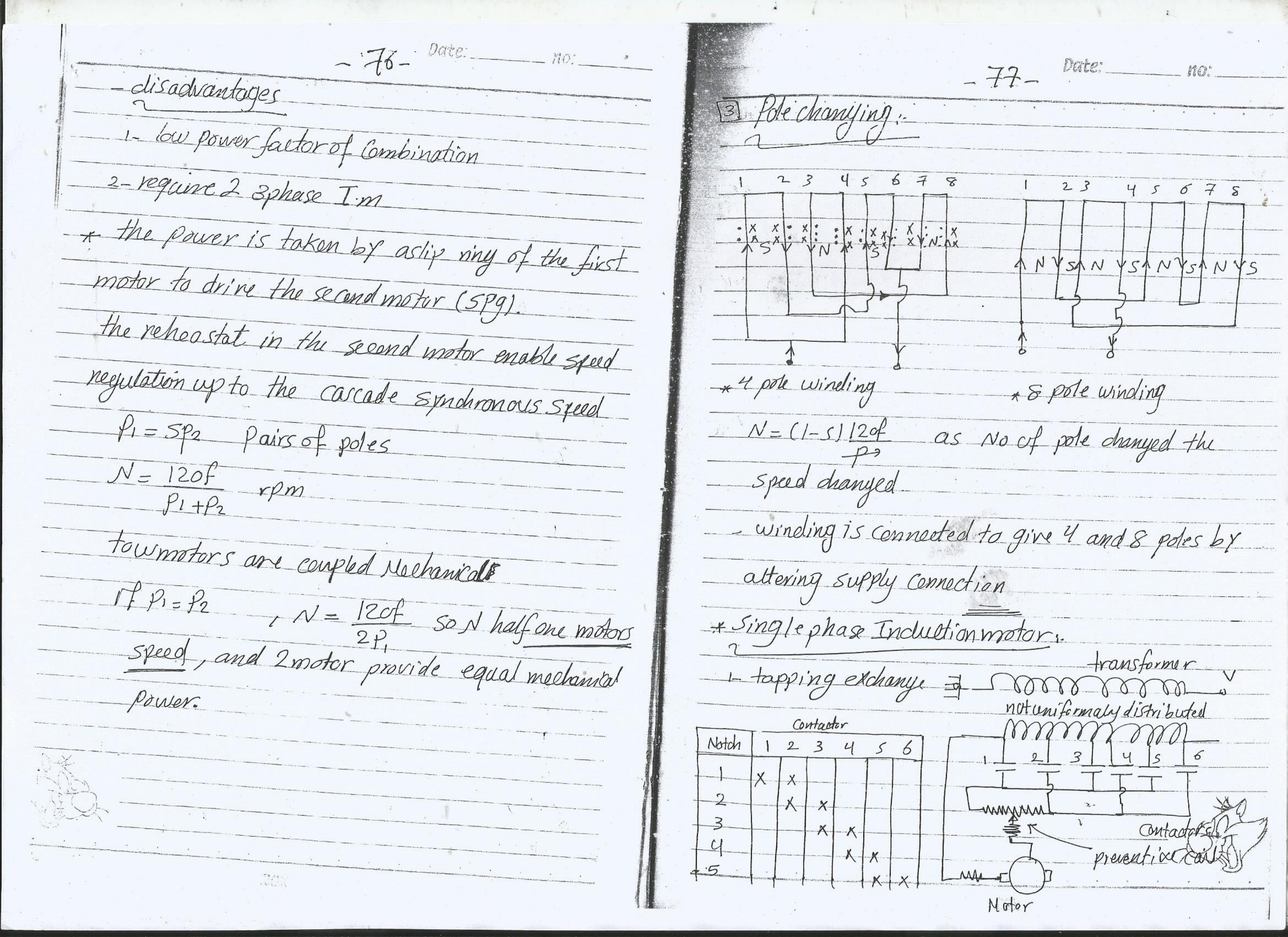
$N = \frac{120f}{P_1 + P_2}$ rpm

tow motors are coupled Mechanically

If $P_1 = P_2$ , $N = \frac{120f}{2P_1}$ so N half one motors speed, and 2 motor provide equal mechanical power.



3 Pole changing :-




* 4 pole winding * 8 pole winding

$N = (1-S)\frac{120f}{P}$ as No of pole changed the speed changed.

- winding is connected to give 4 and 8 poles by altering supply connection

* Single phase Induction motor :-

1- tapping exchange



| Notch | Contactor 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | X | X | | | | |
| 2 | | X | X | | | |
| 3 | | | X | X | | |
| 4 | | | | X | X | |
| 5 | | | | | X | X |

- there are five notch at each position two Contactors are closed.
- the volt Can be reducing at start without a resistance so large saving in energy.
- the motor take its power from transformer secondary through tap exchange by a contactors.

* Preventive coil:-

- to ensure proper operation to prevent short circuit at transformer secondary.
- at each notch there are two contactor closed.

* advantages:-

- each notch is a Runing position so wide speed change
- low losses because high efficiency transformer.

* Electric braking

plugging | rheastatic | regenerative



- in certain train there are mechanical or electric wheal brakes.

1] plugging:-

- in plugging the torque is reversed by reverse of armature current or field current. but not (both). its better to current ($I_a$) this for dc Motor.



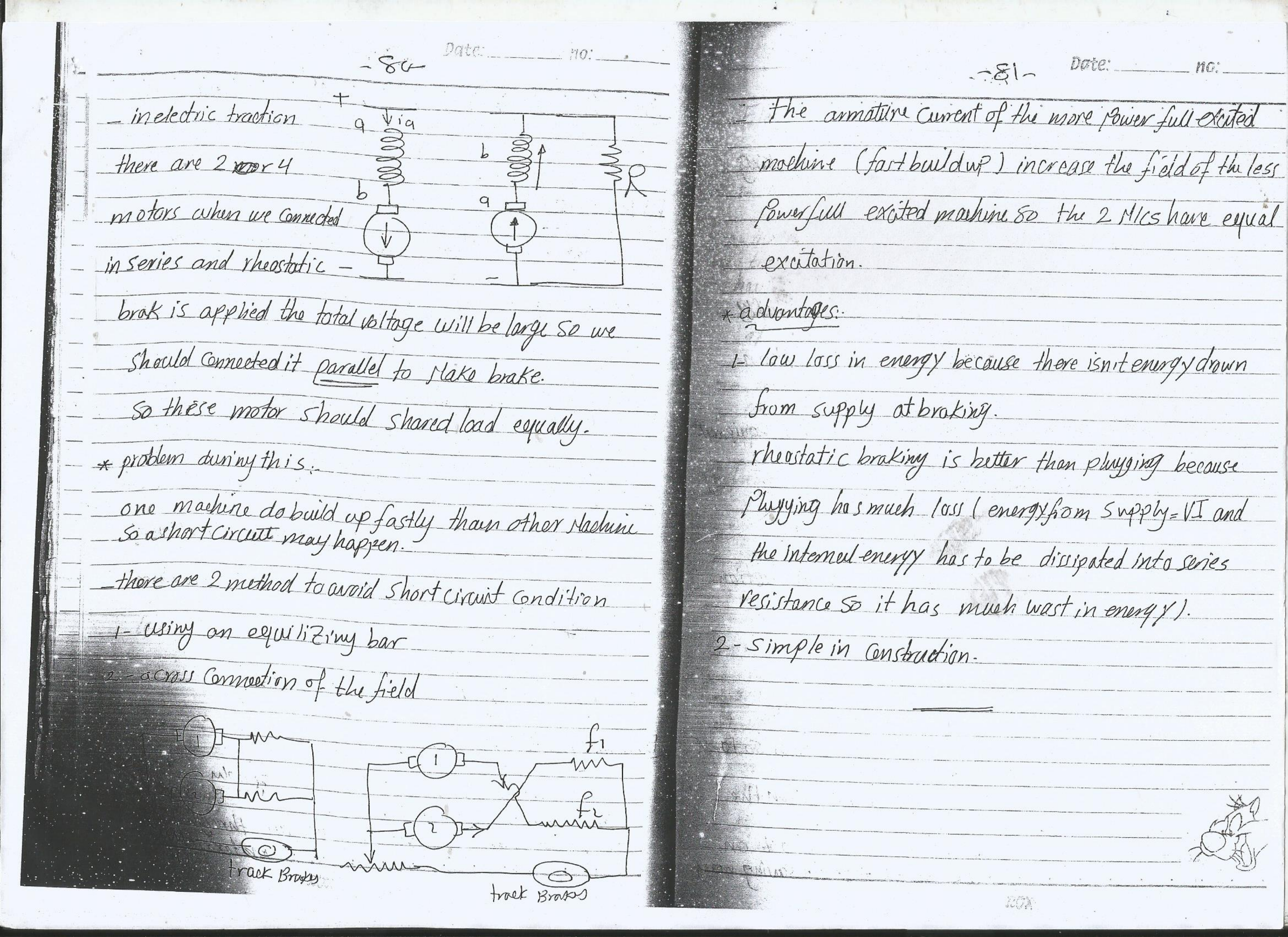
* it has high copper loss in series resistance. for three phase I.M plugging can happen by reversing direction of rotation of magnetic field by reversing one phase.

$$I = \frac{E+e_b}{R_a+R_{Limit}}$$

- Construction is Simple (advantages).

2] rheastatic braking:-

- the motor is disconnected from the supply and connected to a resistance
- the kinetic energy that motor gain through Running is dissipated through resistance and motor act as generator





- in electric traction there are 2 or 4 motors when we connected in series and rheostatic brak is applied the total voltage will be large so we should connected it parallel to make brake.

So these motor should shared load equally.

* problem during this:

one machine do build up fastly than other machine so a short circuit may happen.

- there are 2 method to avoid short circuit condition

1- using an equilizing bar

2- across connection of the field





The armature current of the more power full excited machine (fast buildup) increase the field of the less powerfull excited machine so the 2 M/cs have equal excitation.

* advantages:

1- low loss in energy because there isn't energy drawn from supply at braking.

rheostatic braking is better than plugging because plugging has much loss (energy from supply = VI and the internal energy has to be dissipated into series resistance so it has much wast in energy).

2- simple in construction.

## * Regenerative Braking:-

* advantayes and disaduantges of regenerative Braking on level route ??

* disadvantages:-

1- So far as dc equipments are concined are briefly.
2- the motors are larger, heavier and more cost than ordinary equipments.
3- increase the maintenance charges on the electrical equipment
4- Control and operation become Complicated.
5- increase weight of the train and No of motor
6- additional equipment to control the regenerative action of the motors.

* advantage:-

1- reduce energy Consumption
2- " wear or brake shoes and wheel tyres so lower maintanenca cost of these parts.
3- small amount of brake dust produce when the mechanical brakes is applied.
4- reduetion of energy consumption reach to 10% on level route but in undulating routes the saving may reach to 20%.



* Electric Regenerative on main line and mountain Railways is essential dueto:-
1- the large amount of energy available during the descent of the gradiants.
2- the large use of electric locamotives
3- the operating Conditions permitting the use of motor having aconstant speed characteristices.
4- the runing cost have to be found to be only about 75% of those when the lines were operated with steam locomotive through down gradiants.
5- the recoperated energy being in order of from (60-80 of the energy Consumption for the up Journey with the same train.

## * French method of Regenerative braking:-

- forone motor

* during motoring:-

- the machine act aseries motor the field winding and auxillary winding are in Parallel with it

* during generation:-

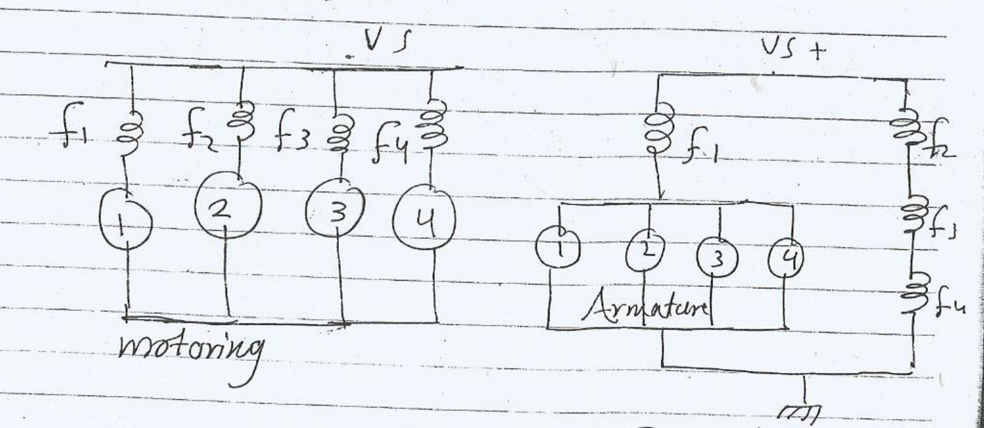
- the auxillary winding are switched in series and the machine act as a shunt generation.

* For several motor:-

- during motoring: the field windings are in series with their own armature
- during generation: the motor circuit are in parallel (all armature in parallel)

- in series with one field winding and other field winding work as auxillary winding (in series) parallel to one field winding and motor circuit.

* assume four motors:




- the auxiliary winding connecting across the supply to help the main field winding to do build up fastly to return power to supply through braking.

* advantage:-
  - there is not need any for auxiliary winding because some field winding do its operation.



[2] metropolitan-Vickers regenerative system:-

- this system use an auxiliary generator it can be either one of train motor or special H/C
- the magnitude of the regenerative current is controlled by varying the field strength of auxiliary generator

Vs +ve
main field
traction motor
Vg
Vf
stabilizing resistance
Rs
I'
Seperate excited aux generator
N11
-ve

- the stabilizing resistance is used to
  1- prevent current surges when the motor crosses from one section of supply to another.
  2- to compensate for variable line volt.

$Vg = Vs + I'Rs$

$I'R = Vg - Vs$

$I = I' + I_{au}$

$V_{au} = Vf + I'Rs$

Vau is const as a seperatly generator.

if Vs increase $\Rightarrow I\downarrow \Rightarrow I'\downarrow \Rightarrow I'Rs\downarrow \Rightarrow Vf\uparrow \Rightarrow Vg\downarrow$

* steps:-
- regenerative braking used down to about 10 m.p.h.
- the rheostatic braking down to 4 mph and finally mechanical braking untill stand still 0 m.ph

## 3 Metadyne:

علم - it is a method of varying a volt by acheives smooth control of speed and starting of dc/M/C without dissipating energy in a resistance.

تعريف - its a rotating transformer for dc power with a variable turn ratio. so it can draw power from dc source and deliever it at a constant current and variable voltage to an accelerating motor.

- fig(a):
  ordinary machine with two poles and two brushes
- fig(b):
  metadyne with four pole and four brushes
  - $I_1 \Rightarrow$ produce primary flux
    this primary flux produce emf between (B, D) brushes.
  - $I_2$ flow through load.

fig(c): $I_2$ produce a secondary flux this secondary flux produce emf between (A, C) brushes which neutralize the applied voltage ($E_1$)

from fig(b) $E_2 = K I_1$ neglect loss
$E_1 = K I_2$

K -> constant depend on construction of M/C and speed

$$E_1 I_1 = E_2 I_2$$



input and output power are equal (like transformer)

if $E_1$ is const, $I_2$ = const and load resistance change

$I_2$ = const, $I_1$ increase and $E_2$ increase.

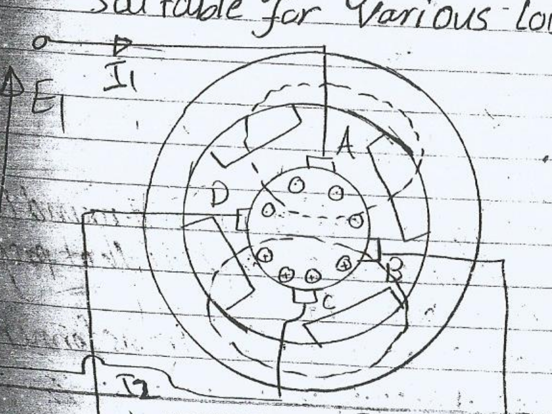
عندما يصل الموتور إلى السرعة max فإنه من الضروري أن نقلل التيار

إلى $I_2$ rated value وللتحكم في هذا بواسطة

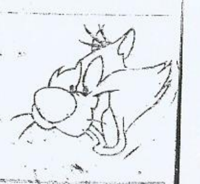
↓ Variator or regular winding.

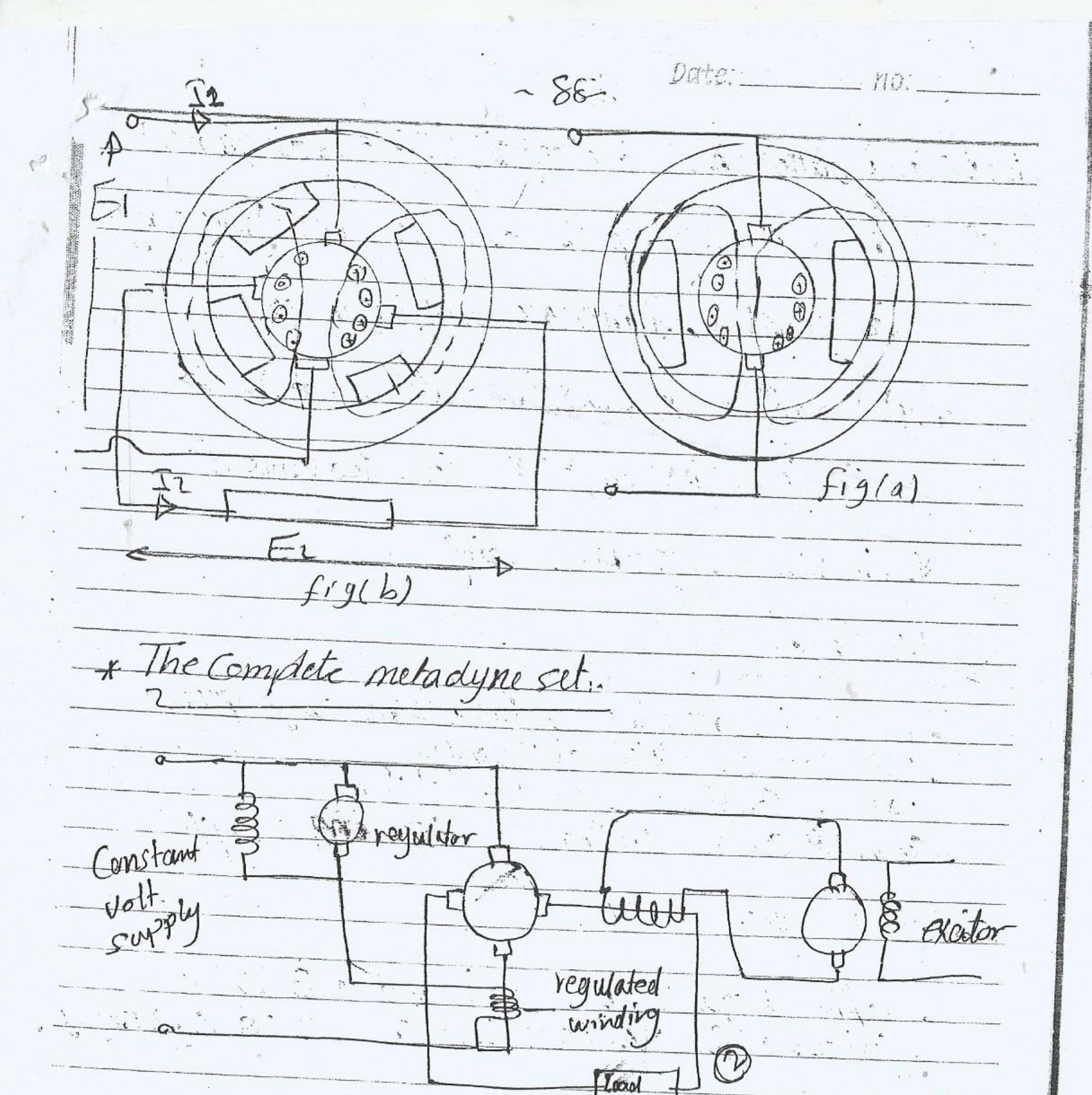
- advantage:
  - no switch require so there is no surge appear
  - low loss and high efficiency
  - giving constant current at start
  - smooth control without dissipating energy.

* disadvantages:
  - after beganing we can't reduce $I_2$ to be suitable for various load. so we used variator wdg



fig(c)






* The Complete metadyne set.

- Variator winding:
  - its a winding feed from dc exciter wound round the pole and produce of flux with or opposite that produced by $I_2$ so we can control $I_2$
  - this a variator winding destroys the transformer property of the metadyne where.



$E_1 = K I_2 + k_v I_v$ (not transformer property)

when $I_v = 0 \Rightarrow E_1 = K I_2$ (transformer property)

+ve variator excitation when flux produced is in same direction that produced by $I_2$

(-ve) variator exciter when flux produced opposite direction of $I_2$ flux.

* regulator winding:-

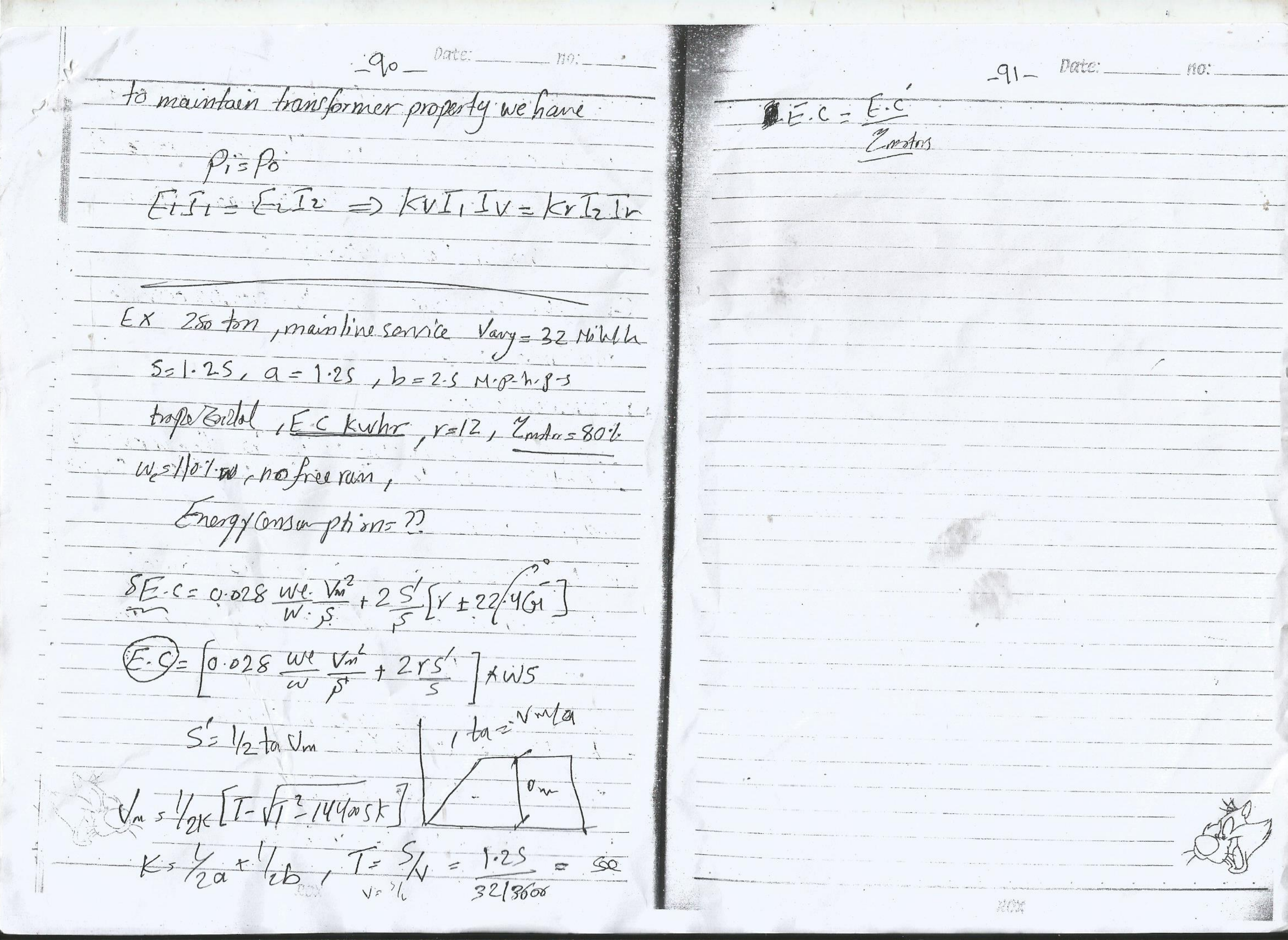
- used to maintain metadyne it's transformer property
- it produce of flux this flux effect the output current and power output.
- if this regulator current is adjusted correctly the output power remains constant to input power

$E_2 = K I_1 + K_r I_r$

$I_r, I_v \rightarrow$ variator, regulator current
$K_v, K_r \rightarrow$ constant of M/C

$P_i = E_1 I_1 = K I_1 I_2 + K_v I_1 I_v$

$P_o = E_2 I_2 = K I_1 I_2 + K_v I_2 I_r$





to maintain transformer property we have

$P_i = P_o$

$E_1 I_1 = E_2 I_2 \Rightarrow K V I_1 I_V = K r I_2 I_r$

---

Ex 250 ton, mainline service $V_{avg} = 32$ kM/h

$S = 1.25$, $a = 1.25$, $b = 2.5$ M.p.h.p.s

trapezoidal, E C kwhr, $r = 12$, $\eta_{motors} = 80\%$

$W_e = 110\%$ W, no free run,

Energy consumption = ??

$$\delta E.C = 0.028 \frac{W_e}{W} \cdot \frac{V_m^2}{S} + 2 \frac{S'}{S} [r \pm 22.4 G]$$

$$E.C = \left[ 0.028 \frac{W_e}{W} \frac{V_m^2}{S} + \frac{2 r S'}{S} \right] * W S$$

$S' = \frac{1}{2} t_a V_m$ , $t_a = V_m / a$

$$V_m = \frac{1}{2K} \left[ T - \sqrt{T^2 - 14400 S K} \right]$$

$K = \frac{1}{2a} + \frac{1}{2b}$ , $T = \frac{S}{V} = \frac{1.25}{32/3600} = 50$

$V = S/t$



$$E.C = \frac{E.C'}{\eta_{motors}}$$